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Biogas in Uganda and the SDGs: A Comparative Cross-Sectional Fuel Analysis of Biogas and Wood Fuel; Case study of Iganga District

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled Biogas in Uganda and the SDGS: A Comparative Cross-Sectional Fuel Analysis of Biogas and Wood fuel; Case Study of Iganga District independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague date

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Phiona Jackline Mukisa

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Abstract

This study aims at investigating the use of small-scale biogas technologies vis-à-vis wood-fuel and their implementation benefits in terms of the socio-economic, environmental, health and climate aspects in relation to the SDGs attainment among households in the rural areas of Iganga district, Eastern Uganda. A mixed method design was used with a sample population of 300 households in addition to 6 local government officials and 8 NGOs. 262 questionnaires were returned after data collection; 6 government officials and 6 out of 8 NGOs were interviewed, data was coded and analysed using Microsoft excel and the Statistical Package for Social Sciences (SPSS) version 20. Household perceptions on use of biogas technology showed that users reflects clean gas production with 46.9%, biogas plants being easy to maintain and operate with 34.5%, low installation costs with 4.3% while those that had other reasons and missing data at 4% and 10.2% respectively. The motivating factors for its use included biogas being smoke free, women and children getting time to engage in other development activities and reduced time spent on cooking. MANOVA test results for biogas use having a significant impact on SDG attainment showed there was a significant impact of using biogas vis-à-vis wood fuel towards SDG attainment with F-ratios (.71, .56 & .88) greater than the a = .05. One-Way ANOVA test reported that access to biogas knowledge and technical expertise were the main variables hindering the adoption and use of biogas technologies besides other factors at a=.05 where the variances of each comparison group were equal meaning the overall F-ratio for ANOVA were significant. The findings also showed that the government has played little or no role in promoting biogas usage compared to the NGOs that have played a remarkable role in biogas promotion and usage. The approaches used by the government (top-down approach) in development of renewable energies has impacted negatively on the acceptability and sustainability of the initiatives implemented. Therefore, it is recommended that the government properly revises the development and implementation policies and frameworks on renewable energies in addition, to putting an emphasis on subsidy facilities to increase the adoption rates.

Key words: Biogas, energy consumption, fuel sources, domestic energy, biogas energy, biogas technology, waste management, Uganda

Muhtasari wa Kiswahili

Utafiti huu wenye lengo la kuchunguza matumizi ya teknolojia ndogo ndogo za biogesi dhidi ya mafuta ya mbao na faida zao za utekelezaji kwa kuzingatia masuala ya kijamii na kiuchumi, kimazingira, afya na hali ya hewa kuhusiana na SDGs kufikia miongoni mwa kaya katika maeneo ya vijijini ya wilaya ya Iganga, Mashariki mwa Uganda. Ubunifu wa mbinu mchanganyiko ulitumika na sampuli ya kaya 300 pamoja na viongozi 6 wa serikali za mitaa na mashirika yasiyo ya kiserikali 8. Maswali 262 yalirudishwa baada ya ukusanyaji wa data; Maafisa 6 wa serikali na mashirika yasiyo ya kiserikali ya 6 kati ya 8 walihojiwa, data ilipigwa na kuchambuliwa kwa kutumia Microsoft excel na Kifurushi cha Takwimu cha Sayansi ya Jamii (SPSS) toleo la 20. Mtazamo wa kaya juu ya matumizi ya teknolojia za biogesi ulionyesha kuwa digesters za gesi zinazalisha gesi safi na 46.9%, digesters kuwa rahisi kudumisha na kufanya kazi na 34.5%, gharama za ufungaji wa chini na 4.3% wakati zile ambazo zilikuwa na sababu nyingine na kukosa data kwa 4% na 10.2% Vipengele vya kuhamasisha matumizi yake ni pamoja na biogesi kuwa moshi bure, wanawake na watoto kupata muda wa kujihusisha na shughuli zingine za maendeleo na kupunguza muda uliotumika kupika. Matokeo ya mtihani wa MANOVA kwa matumizi ya biogesi kuwa na athari kubwa juu ya upatikanaji wa SDG yalionyesha kulikuwa na athari kubwa ya kutumia mafuta ya mbao za biogesi kuelekea kufikia SDG na uwiano wa F(.71, .56 & .88) kubwa kuliko = .05. Mtihani wa Njia Moja Anova uliripoti kuwa upatikanaji wa maarifa ya biogesi na utaalamu wa kiufundi ndio vigezo vikuu vinavyozuia kupitishwa na matumizi ya teknolojia za biogesi kando na mambo mengine kwa a =.05 ambapo vigezo vya kila ulinganisho kundi hilo walikuwa sawa maana ya uwiano wa jumla wa F-kwa ANOVA yalikuwa muhimu. Matokeo hayo pia yalionyesha kuwa serikali imekuwa na jukumu dogo au hakuna jukumu la kukuza matumizi ya biogesi ikilinganishwa na mashirika yasiyo ya kiserikali ambayo yamekuwa na jukumu la ajabu katika kukuza biogesi na matumizi. Mbinu zinazotumiwa na serikali (mbinu ya juu chini) kwa maendeleo ya nishati mbadala zimeathiri vibaya ukubalifu na uendelevu wa mipango iliyotekelezwa. Kwa hiyo, inashauriwa serikali irekebishe ipasavyo sera za maendeleo na utekelezaji na mifumo ya nishati mbadala. Aidha, ili kuweka msisitizo katika vituo vya ruzuku ili kurahisisha viwango vya kupitishwa.

Maneno muhimu: Biogesi, matumizi ya nishati, vyanzo vya mafuta, nishati ya ndani, nishati ya biogesi, teknolojia ya biogesi, usimamizi wa taka, Uganda.

Abstrakt

Tato studie se zaměřuje na výzkum využití malých bioplynových stanic v porovnání s palivovým dřívím a srovnání přínosu jejich implementace z hledisek socioekonomických, environmentálních, zdravotních a klimatických, ve vztahu k dosažení Cílů udržitelného rozvoje mezi domácnostmi ve venkovských oblastech okresu Iganga ve východní Ugandě. Byla použita smíšená metoda se vzorkem populace zahrnujícím 300 domácností, 6 úředníků místní správy a 8 nevládních organizací. Během sběru dat bylo sesbíráno 262 dotazníků z domácností; bylo provedeno interview se 6 vládními úředníky a 6 z 8 nevládních organizací. Data byla kódována a analyzována pomocí aplikace Microsoft Excel a statistického softwarového balíčku pro sociální vědy (SPSS) verze 20. Pohled domácností na používání bioplynové technologie ukázal, že malé bioplynové stanice produkují čistý plyn ve 46,9 %, bioplynové stanice se snadno udržují ve 34,5 %, náklady na instalaci jsou vnímány jako nízké ve 4,3 % a ty, které měly jiné důvody, a chybějící údaje na 4 %, respektive 10,2 %. Mezi motivačními faktory pro používání bioplynových stanic bylo prostředí bez kouře, více času pro ženy a děti na zapojení se do jiných rozvojových činností, a zkrácení času stráveného vařením. Výsledky testu MANOVA ohledně významnosti používání bioplynu na dosažení Cílů udržitelného rozvoje ukázaly, že použití paliva z bioplynu namísto dřeva mělo významný dopad s F-poměrem (,71, ,56 a ,88) větším než a = ,05. Jednocestný test ANOVA ukázal, že dostupnost znalostí o bioplynu a technických odborných znalostí byly hlavními proměnnými, které bránily přijetí a používání bioplynu, kromě jiných faktorů při a=,05, kde odchylky každé srovnávací skupiny byly stejné, což znamená, že celkový F-poměr pro ANOVA byl významný. Zjištění rovněž ukázala, že vláda sehrála malou nebo žádnou úlohu při podpoře využívání bioplynu ve srovnání s nevládními organizacemi, které sehrály důležitou úlohu při propagaci a používání bioplynu. Přístup k rozvoji obnovitelných energií uplatňovaný vládou (přístup shora dolů) měl negativní dopad na akceptovatelnost a udržitelnost prováděných iniciativ. Proto je doporučeno, aby vláda adekvátně zrevidovala rozvojovou a prováděcí politiku a rámec pro obnovitelné energie, aby kladla důraz na dotační nástroje za účelem zvýšení míry přijetí těchto technologií.

Klíčová slova: bioplyn, spotřeba energie, zdroje paliva, domácí energie, energie z bioplynu, technologie bioplynu, nakládání s odpady, Uganda

Contents

List of tables

List of figures

ANNEXES

List of the abbreviations

AD	- Anaerobic digestion
CBOS	- Community Based Organizations
ECP	- Electricity Connections Policy
GHG	- Green House Gases
HH	- Household
HHH	- Household Head
KCCA	- Kampala Capital City Authority
MEMD	- Ministry of Energy and Mineral Development for Uganda
MSW	- National Agricultural Research Organization
NARO	- National Agricultural Research Organizations
NGO	- Non- Government Organization
SDGs	- Sustainable Development Goals
SNV	- Stichting Nederlandse Vrijwilligers
SPSS	- Statistical Package's for Social Sciences
UBOS	- Uganda Bureau of Statistics
UDBP	- Uganda Development Biogas Programme
UETCL	- Uganda Transmission Company Limited

1. Introduction

This chapter contains the background of the study, problem statement, and research contribution.

Energy is a very important necessity in the lives of people and without access to clean and affordable energy, it can negatively affect the development process of any country in terms of the socio-economic, environmental, climatic and health. Aspects that are related to the sustainable development goals (SDGs) of 2030.

Biogas is a renewable, flammable energy that can be produced from the breakdown of organic matter like municipal, animal, industrial and agricultural wastes with the absence of oxygen (O_2) a process known as anaerobic digestion (AD). This biogas energy is mainly composed of carbon dioxide (CO_2) and methane (CH_4) with small quantities of water vapor particles, siloxanes, and hydrogen sulphide (H_2S) that can be used for heating, cooking, lighting, and vehicle fuel.
Access to basic clean and affordable energy services such as natural gas, liquid fuels in the developing world is still an issue to the communities and households. Adoption of biogas energy technologies will mostly depend on the government initiative to come up with solutions to make it popular amongst its people. Surendra eta l; (2014) noted that the percentage of the population that rely on solid fuels such as wood, crop residues, cattle dung, and coal in crude traditional stoves to meet their cooking needs are 45%. In East Africa, biomass is mainly the primary source of energy in the rural areas and is mainly used for cooking. For those with access to organic feedstock like animal feeds, biogas energy can be an alternative for them (IRENA, 2017).

Uganda is endowered with organic wastes that can be used for biogas energy generation. There has been steady increase in the availability of waste streams for example municipal, abattoir and animal wastes over the years of which 1400 ton per day of municipal waste is collected and landfilled of which 90% is organic material (Kampala Capital City Authority (KCCA), 2017). However, rural people are increasingly encroaching on the forests at a very fast rate due to high demand of wood fuel commonly used for cooking in the rural areas, timber for building, charcoal for the urban dwellers and land for agriculture use. Annually, approximately 90,000 hectares of forest cover are lost, making fuel wood scarce in rural areas and increasing price levels of charcoal (Ministry of Energy

& Biomass Energy Strategy, 2014). This imbalance can partly be attributed to weak institutions, uncoordinated implementation of policies between different sectors of the economy, insufficient funding, and limited capacity at all levels which has undermined effectiveness and efficiency in developing and sustainably managing forestry resources in Uganda.

The government of Uganda and different Non-Government Organizations (NGO) have come up with different initiatives as a way of showing their commitment in promoting the use and adoption of biogas technology among the rural households in the recent years. They have tried to empower and educate the mases about biogas digestors, supplied energy bulbs and energy saving stoves to rural households as a way of achieving several SDGs. The government also came up with a renewable energy policy in 2007 that aimed at increasing modern energy supply technologies that are cheaper and clean which reduces on the demand of fuel wood. However, their efforts have not produced significant outcomes.

1.1. Problem statement

Despite all the attempts of the government to address the issue of biogas technology in rural areas of the country through its renewable energy policy that was aimed at achieving 61% of the total energy consumption from modern renewable energy and other initiatives, the adoption rate for the biogas technology is still low and forest cover is disappearing at a very fast rate. No minimum energy specifications were set for each energy resource and those that are available, are still not yet accessible by local people (World Bank, 2019). Therefore, this thesis called for assessment of biogas potential and need for better understanding of biogas energy related matters since the country has available and cheap biomass resources that are collected and landfilled.

1.2. Research Contribution

i. The research seeks to inform policy makers on the sustainable and adaptable approaches to biogas technology development.
ii. In addition, it will add to the existing body of knowledge concerning biogas technologies.
iii. Lastly, it seeks to equip the masses with knowledge and skills about the use of biogas technologies.

2. Literature Review

In different countries, biogas has been and is still a topic of discussion and research in many of scientific papers who deal with many aspects related to its generation. This literature review provides an insight into some of the aspects related to biogas production that will help in addressing the thesis aim.

2.1. Waste Management in Africa

Humans engage in activities that are sources of wastes and still prove to be an issue as it was in the pre-historic period (Chandler et al., 1997). Volumes of generated wastes started in the sixteenth century as people moved from rural to urban areas due to industrial revolution. However, in the nineteenth century, governments tried to improve public health hence, proper waste disposal mechanisms emerged (Wilson, 2007).

The Urban authorities are in change of waste management services in Africa and the services are mainly concentrated in large cities leaving rural areas with hardly no waste management systems, yet a minimal share of waste is recovered and reused (Okot, 2012**)**. Waste disposal methods depend on the kind of waste generated and these methods are influenced by various factors including frequency, quantity, kind, and type. The three commonly applied waste disposal methods in Africa are open dumping, sanitary landfills, and controlled dumping of wastes (Arogundade, 2019).

Lack of proper infrastructures, inadequate technical ability, limited financial resources, inadequate laws or policies on waste management, population growth and limited environment awareness are some of the problems African countries are facing. With the available data, it indicates that in 2012, 125 million tons of municipal solid waste (MSW) per annum was generated of which 81 million tons averaging to 65% was generated from sub-Saharan Africa. The MSW generated in Africa is 57% on average and consists of wet wastes, biodegradable, and organic waste. However, the MSW is expected to increase in volumes to 244 million tons by 2025 (Scarlet et al., 2015).

The waste stream of great concern in African is plastic with an estimation of 13% which is dumped on open grounds. The amount of wastes that are hazardous are increasing yet little awareness of its management and nature is lacking. Food waste is also becoming a problem for the continent as more than third of the food is wasted yet the continent has high levels of poverty, hunger, and malnutrition (figure 1).

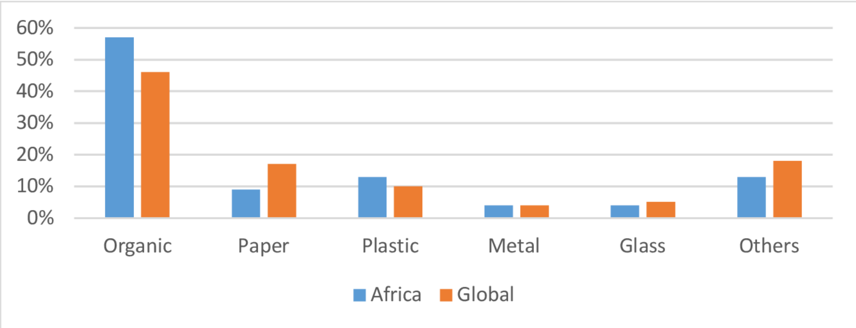


Figure (1): A Comparison of MSW in Africa and the world

Data source: Godfreyet.al., (2019)

2.1.1. Waste Management in Uganda

Waste in East Africa is collected directly from the sources by use of refuse trucks and taken to waste disposal sites (Rotich et al., 2006). But due to an increase in population growth and inadequate funds, the municipal solid management system shifted from colonial days in the 40s to 60s when their services were efficient enough to a partnership system where private sector is involved (Okot et al., 2011).

In Uganda, waste management is one of the problems the urban authorities face today as the volumes of waste produced surpasses their financial and technical capacity to dispose it off (Water Aid, 2011). It is the responsibility of KCCA to provide solid waste management services to all the five divisions of Kampala city (Rubaga, Kawempe, Nakawa, Makindye and Kampala central division) mandated in the Local Government Act of 1997. Solid waste is collected from market areas, hospital, households, city centres and from industries**.** It is estimated that 1500 tons of solid waste is generated per day and only 40% to 50% of the garbage is disposed. 80% of the garbage is organic matter which makes it difficult to be handled (KCCA, 2020).

The typical household waste in Uganda mainly consists of food leftovers, kitchen waste, vegetables, fruit peels and skins with more wastes generated from low income residential areas and the least wastes generated from marketplaces. It is sometimes mixed with banana peels, stiff maize porridge(posho) among others which are fed to animals and later the manure got from the animals is used for biogas production (Tumwesige, 2013; Kinobe, 2015).

To improve the situation, private companies are contracted to help with collection of wastes to improve on the city sanitation. However, less than half of the generated wastes is collected leaving the remaining uncollected wastes to be dumped in streams, open areas, open drainage channels and other areas that are not easily accessed by the waste management collection trucks thus creating health and environment problems (KCCA, 2020)

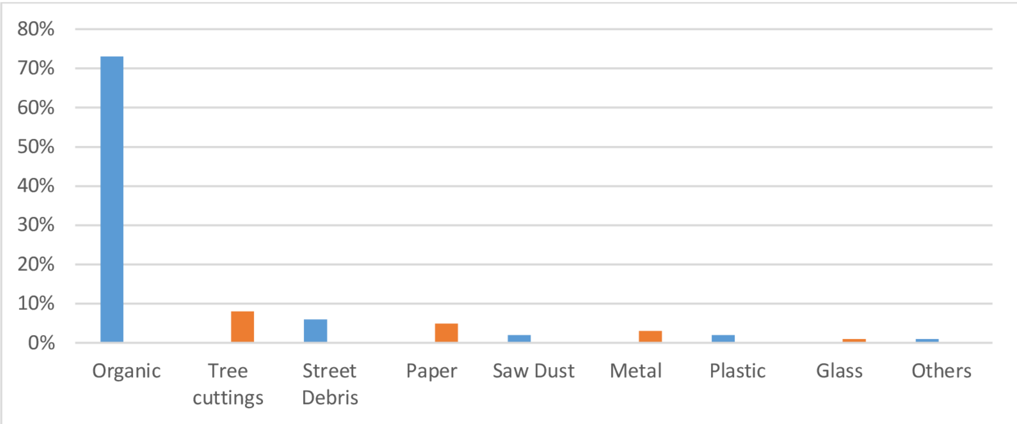


Figure (2): Waste Composition land filled by KCCA and Private Companies in Uganda
Data source: Global Green Growth Institute Uganda, (2017).

The wastes are sometimes collected and transported to transfer points demarcated by the urban council by households, market traders and commercial premises themselves or hired informal labour who before collection by the urban council or private companies. The large institutions like schools, hospitals, industries, large markets, and shopping malls have their own transfer stations served by trailer bunkers or waste containment facilities. NGOs and CBOs also are involved in waste management process of collection, recycling, and disposal in some parts of the country and try to sensitize people on the reuse, recycling of wastes to alleviate the problem of environment degradation. They teach people on how to make briquettes and biogas from wastes (Tukahirwa, 2011).
There are also informal waste pickers known as scavengers who move to rescue the public by picking of wastes especially metal and plastics from public bins, disposal sites and along streets and exchange them for money. They sometimes move from home to home, markets, and other establishments for scrap (Wang et al., 2008). However, all those involved in the process of waste collection and disposal do not save the situation of poor waste management practices in the country as there is no environment awareness amongst

the population and lack of active waste management laws for enforcement of proper practices.

2.2. Biogas in Africa

In the African continent, access to electricity and modern energy for cooking is still an issue for both commercial and household activities and over 2.7billion people in sub-Saharan Africa form the majority population that rely predominately on traditional biomass for cooking globally (Sehgal, 2018). The global total final energy consumption which is said to have been supplied in 2016 from traditional biomass was 7.8% and 10.4% from modern renewable energies that included biogas for electricity and heat generation and biomass fuels inform of solid biomass (Ahammad et al., 2016).

The African continent has high potential in biogas generation though there has been little utilization of the resources to develop the sector due insufficient finances, technical problems and insufficient laws that could encourage its production and use (Clemens et al., 2018; Laramee, et al., 2013). The installed biogas systems in Africa and Asia are majorly family-sized plants and they generate biogas energy for use at household levels. However, in China and India, installations of large-scale biogas systems are on the rise for heat and electricity appliances (Cheng et al., 2014). This indicates there is progress being made in the generation of biogas on small-scale though still lacking in large scale generation of biogas energy (Rupf et al., 2016). If the resources are utilized maximumly to develop the sector, the large-scale biogas systems potential could be of great importance to schools, hospitals, wastewater and excreta management institutions and municipalities, commercial buildings, solid waste management municipalities, crop and livestock farms, universities, and medium and large fuel processing industries because they generate large amounts of wastes (Parawira, 2009).

Nigeria the most populous country in Africa, its biogas potential was estimated at 6.8million cubic meters per day from animal manure, and an equivalent of 482MW of electricity from 913,400tons of MSW (Aliyu et al., 2015). In Kenya, 624GWh of electricity from agro-industrial waste and wastewater using biogas technology was generated and Kenya had the largest grid-connected biogas plant situated in Naivasha in Africa by 2017 producing 2.2MW and selling surplus power to the grid at $0.10 per kW.

The producing company used 0.2MW and 2MW surplus power was fed into the grid to meet the needs of the 6000 rural homes (Mugodo et al., 2017).

In other African countries, studies carried out on biogas potential on estimated raw materials present for AD showed that there is high potential for East and West Africa where some of the installed biogas systems are in operation. However, there is minimal scientific literature that shows the technologies deployed when installing the commercial biogas systems in Africa expect for South Africa that uses plug low, lagoon, and up-flow sludge blanket (Rupf, 2016).

Africa being described to have a lot of potential in developing the biogas energy market, its resources have not been maximized fully. As a continent, it has lessons to learn from other countries like China and Germany that are said to be among the leading producers of biogas energy. However, their systems or measures employed cannot wholly be copied and implemented in Africa because successful biogas programmes all depend on active energy and environmental policies, promotion of research and development, and awareness creation among other support systems besides availability of feedstock which are in adequate in Africa.

2.2.1. Biogas in Uganda

The history of biogas technologies in Uganda is traced way back in 1950s being introduced by the Church Missionary Society (CMS) (Nabuuma et al., 2004). From the 1980s to 1985, biogas technologies were under the African Energy Program and there was construction of demonstration plants and fuel-efficient stoves by the Commonwealth Council. Later, a Chinese fixed dome design plant was built in the Eastern region of the country (Ocwieja, 2010).

The number of systems estimated to have been in existence by 2008 were around 800 compared to 100 in 1990. 15-20% was the rate at which the technologies were deserted being associated with the systems constructor limited skills and household's inadequate operation and maintenance (UNBP, 2010). In a survey made by Lutaaya, (2013) on quality and usage of biogas digesters in Uganda, and Oluka (2013) article in Daily Monitor newspaper, it was found out that animal, human and agricultural wastes are the commonly used feedstock for biogas generation.

Different digester designs are used globally but for the case of Uganda, the fixed dome and floating drum digester designs are the commonly used which are however expensive for the average households to afford (Walekhwa et al., 2009). The Ugandan government created the Uganda Domestic Biogas Programme (UDBP) in 2008 aimed at making the rural and semi-urban population benefit from the use of clean energies for cooking, lighting while using bio-slurry through dissemination of domestic bio-digesters (Heifer International, 2020). These bio-digesters were implemented in three different Ugandan regions; Eastern, Central and Western Uganda being promoted by the Ministry of Energy and Mineral Development for Uganda (MEMD) and the National Agricultural Research Organization (NARO) with a helping hand from NGOs like Heifer International Project (HIP) among others (IEA, 2011).

In addition, the African Biogas Partnership Program (ABPP) and the Dutch government, supported the adoption of bio-digesters that were constructed between 2009-2013 in Uganda, Kenya, Burkina Faso and Tanzania and by 2016, 25% of them were not functioning which lead to campaign launching for repairing of the non-functioning plants (Clemens, 2018).

2.3. Renewable energy and Biogas Policies in Uganda

The energy sector is a major contributor to the country's treasury resources from fuels taxes, levy on transmission, bulk purchases, foreign exchange earnings from power exports, and VAT on electricity. License fees, royalties, and considerable public investments have been injected into the electricity supply sector and it has enabled the country gain economic growth averaging 6% per annum for the last decades, 2010 to 2013 (MEMD, 2019). Demand for the electricity has been growing at an average of 10% per annum following liberalization of the country's economy in 1987 and structural reforms program implementation (Energypedia, 2020). However, there is poor quality and inadequate electricity services, low consumption of modern energy forms, and dominance of wood fuel seen especially in the rural areas (SE4ALL Initiative, 2013).

The sector is divided into four subsectors and governed by the Ministry of Energy and Mineral Development (MEMD) which formulates, implements, and monitors the energy policies (Nafuna, 2013). The formulation of these policies have been based on three contexts; the international and regional linkages of the sector; the existing economic, social and environmental policies which are the pillars of sustainable development; and the nature and linkages of the energy sector with other sectors (MEMD, 2002).

The subsectors include the petroleum sub-sector that governs the upstream, middle stream and downstream industries; power subsector concerned with the generation, transmission and distribution of electricity including rural electrification; new and renewable sources of energy subsector; and the atomic subsector where energy use in Uganda is mainly in the agriculture and health sector although very limited.

The sector has both the legislative frameworks and policies that govern it. and the first energy policy was implemented in 2002 with the main focus on guiding the energy sector and meet the energy needs of the people for social and economic development in an environmentally sustainable manner (Nafuna, 2013; MEMD, 2019). These include:

2.3.1. Legislative Frameworks, laws, and statutory instruments

i. The 1995 Constitution of the Republic of Uganda (as amended).

ii. The Electricity Act (1999) which stipulates the regulatory framework for the electricity sub-sector and governs the power sub-sector.

iii. Petroleum Supply Act (2003) and Petroleum Act (2013) that govern the petroleum subsector and ensures an adequate, reliable, and affordable supply of quality petroleum products and the 2013 act operationalizes the National Oil and Gas Policy.

iv. The Atomic Energy Act (2008): This act is concerned with the atomic subsector. It regulates the promotion and development of nuclear energy for use in power generation and other peaceful purposes.

v. Biofuels Act (2018): This helps to regulate the production, storage, and transportation of biofuels in addition to blending of biofuels with petroleum products.

2.3.2. Policy Frameworks

i. The Energy Policy (2002): This was formulated with the main goal of meeting the energy needs of the Ugandan population for social and economic development in a way that is environmentally sustainable and it's the main policy that governs the sector.

ii. The Renewable Energy Policy (2007): This was aimed at increasing the share of renewable energy in the national energy mix from 4% in 2007 to 61% by 2017. This was through giving out tax incentives to people who install renewable energy technologies, introducing feed in tariffs, and standardizing power purchase agreement.

iii. The National Oil and Gas Policy (2008): This was geared towards the use of the country's gas and oil resources to help in achievement or reducing of poverty as one of the SDGs under the petroleum subsector. This was formulated after the discovery of oil and gas reserves in the Albertine Graben areas in 2006.

iv. The Electricity Connections Policy (ECP), (2018): This policy was formulated to run for a period of 10 years 2018 - 2027 with a focus on increasing access and provision of cleaner energy for Ugandans. It is focused towards achieving 26% rural access target by 2022 as stipulated in the second Rural Electrification Strategy and Plan, and 30% national coverage target by 2020 as set out in the Second National Development Plan with the help of the adopted subsidy approach as the major financing strategy for single phase connections.

However, in addition to the energy policies, the Climate change policy (2015), the Gender Policy (2007), and the Environment and Social Safeguards Policy (2018) are also used in governing of the sector and play a role in SDG achievement (MEMD, 2019).

2.4. Energy Sources in Uganda

Uganda has plenty of energy resources that are evenly distributed throughout the country although the potential has not been utilized maximumly. A situation that has led to widespread energy poverty in almost all parts of the country (Tumwesigye et al., 2011). It is among the countries with the lowest per-capita electricity consumption rates in the whole world at 215kWh per capita per year and with an average of 552kWh per capita at sub-Saharan African level (Kees et al., 2018; PWC, 2013).

However, there is an enabling environment for that private investors who play a big role in the generation and distribution of electricity but the transmission above 33kV is a public function under the Uganda Transmission Company Ltd (UETCL). The estimation of the energy potential is 2000MW of hydropower, 460 million tons of biomass standing stock, 450 MW of geothermal, 250toe of peat, 5.1 kWh/m2/day and fossil fuels, and presently petroleum which has been discovered in the Western part of the country is at an estimation of 6.5 billion barrels and 1.4 billion barrels are recoverable (Energypedia, 2020).

i. **Hydropower energy**

Hydro power is the main source of electricity generated primarily from Bujagali (255MW), Kiira (200MW), 180MW from Nalubaale plants and accounts for 78% of the installed capacity with 743MW) (IHA, 2018). Bujagali is the largest hydroelectric power plant commissioned in 2012 and is run by the Uganda government in partnership with Sithe Global power, Blackstone, and Aga Khan Fund for Economic Development. The transmission power network consists of primarily 132kV lines connected to various load canters that distribute power to 11kV and 33kV networks among which most of them are extended to Kenya and Tanzania via Tororo district in the eastern of Uganda (Kees, et al., 2018). The country is also constructing other hydropower facilities such as Karuma (600MW), Isimba (183MW), Achwa project (83MW), Muzizi project (44.7MW) and Nyagak project (5.4MW) (iha, 2018).

ii. **Solar energy**

Uganda has a solar irradiation of 1,825kWh/m² to 2,500 kWh/m² per year. Small-scale solar applications are mostly used in rural areas where more than 30,000 solar PV systems have been installed. 5.1 kWh/m2/day is the average solar radiation and has the highest adoption rate in the country. Insolation of solar energy is highest in the north-east part of the country because of its location near the equator with a monthly variation throughout the year of about 20% maximum from 4.5 to 5.5 W/m2 and lowest in the mountainous areas which are the East and South-west parts of the country (UNREEEA, 2020).

iii. **Biomass**

This is the most abundant energy source for majority of the Ugandans. It generates 90% of the primary total energy consumption which is divided into 78.6% wood fuel, 5.6% charcoal and 4.7% crop residues (MEMD, 2014).

Eucalyptus (50%), Pine trees (33%) and cypresses (17%) are the major sources of hard wood and the sugar industry are the only ones that use biomass residues for electricity production. The cement, tile industries and briquette manufacturers use coffee and rice husks for production of heat. Kakira sugar works and Kinyara sugar limited which are some of the many sugar industries in Uganda are the only companies that were licensed by the Ugandan government to generate electricity for sale to the national grid and this is generated from the bagasse with 12MW and 5MW generated in 2010 respectively (https://www.get-invest.eu/market-information/uganda/).

iv. **Wind energy**

Globally, wind energy production is one of the fastest growing renewable energy markets and the global cumulative installed wind energy capacity increased from 6100MW in 1992 to 487GW in 2016. In Africa and Middle East countries, there was a recorded increase in installed cumulative capacity of 418MW and South Africa was the only one with new installations (Muloni, 2012).

Uganda's wind energy resource is insufficient for large-scale electricity generation. Its wind speed in most of the parts of the country are considered moderate according to the metrological record because it ranges from 2m to 4m and the wind measurements have shown an average of 3.7m/s wind speed recently. (NRFC, 2015).

v. **Fossil fuels**

Recently Uganda discovered petroleum in the Western Rift Valley which is Albertine Garbon with 23,000 km2 and 40% of the oil in this basin has been evaluated. Currently, the amount of oil discovered is 6.5billion barrels of which 1.4 billion barrels are recovered. However, Hoima and Kyoga basins are still under investigation (MEMD, 2015).

Despite the discovery of the oil, Uganda imports its petroleum products from overseas since no local production has started. About 95% of the petroleum imports is routed through Kenya and 5% from Tanzania. The consumption of petroleum products is 41.1% petrol, 52.8% diesel and 6.1% kerosene (Energypedia, 2020).

vi. **Geothermal**

The potential of geothermal resources in Uganda is estimated at 450MW and the three prospective target areas are in the Western branch of the East African Rift Valley. These include Buranga, Kibiro and Katwe-Kikorongo with temperature levels between 150 C° and 200 C° enough for generation of electricity that can be used directly in agriculture and industry (UNREEEA, 2020).

vii. **Peat**

Technically, peat is not a renewable energy source technically. However, 250million tons of theoretical peat volumes exists in Uganda as noted in the Renewable Energy Policy for

Uganda, 2007.The available peat energy resources are spread mainly in the Western and South-Western Uganda that has the desired characteristics that are better than other parts of the country. 10% of the peat maybe the available volume for power generation and the remaining would be adequate for generation of about 800, MW in the next 50 years due to the varying quality of the peat (ERA, 2018).

In conclusion, regardless of the availability of all the energy resources, the country's energy sector faces different obstacles that hinders it potential to maximumly utilize the resources and these include, Lack of a fully financial ecosystem that is fully functional and Lack of an integrated power sector planning among others (Power Africa, 2018).

2.5. Generation and Utilization of biogas energy

Acceptance or rejection of any technology is a decision that is either positive or negative and must have gone through a series of steps to come into a conclusion (Rogers, 1983). The diffusion process is more of socialization between two or more people and can go through different channels like social media, designed and implemented policy measures that enable people to have access to useful information (Chem, 2009).

Over the past 15 years, biogas generation has steadily gained considerable thrust. However, there are differences that exist among country sector development as some countries have rapidly developed the biogas industry while others most especially Africa are just developing despite the existing potential of the feedstock (IRENA, 2018). Europe was and is the leading continent in the biogas sector with the highest number of installed biogas plants and Central America plus Caribbean being with the least installed biogas plants by 2015 (American Biogas Council, 2015).

The uses of biogas energy differ from one nation to another due to different variables such as government policies, government incentives and energy prices. Some countries generate biogas energy for cooking and lighting, while others generate it for electricity and upgraded methane to act as vehicle fuel (IEA, 2018). IRENA (2018) noted that generation of biogas capacity reached 16.9GW in 2017 from 6.7GW in 2008 and that other countries use biogas as a means of dealing with wastes while others as a source of substrate.

Table (1): Development of Biogas plant Capacity Globally

	World	Africa	Asia	Central America & Caribbean	Eurasia	Europe	Middle East	North America	Oceania	South America
2008	6699	14	83	4	34	4474	12	1715	260	103
2009	8241	14	152	4	56	5873	16	1728	267	131
2010	9467	14	261	4	72	6871	24	1793	270	159
2011	11358	16	337	10	91	8471	32	1946	271	184
2012	13137	19	435	10	134	9752	34	2257	275	222
2013	13872	20	585	12	163	10141	39	2425	265	223
2014	14880	20	764	11	205	10770	47	2547	274	243
2015	15482	35	860	19	253	11183	58	2524	278	273
2016	16440	36	978	20	298	11620	58	2610	278	543
2017	16915	40	1115	23	347	12064	58	2634	279	355

Data source: IEA Bioenergy Task 37, (2018).

2.6. Biogas as a Domestic Energy

Biogas technologies improve people's wellbeing, and 150 million people benefit from using it (SNV, 2009). It is mainly used in developing countries, and households with some income and those with a reliable source of organic wastes practically make good use out of it (IRENA, 2017). Approximately 50 million biogas-cook stoves have been installed globally yet the population that use traditional cooking stoves dependent on wood and charcoal is 3 billion (IRENA, 2015).

Several appliances for cooking, lighting and power generations have been innovated due to biogas technology installations (Kumar, 2010). The appliances include biogas cookers, stoves, lamps, radiant heaters, incubators, refrigerators, and lastly fuelled engines (Energypedia, 2016). However, among all the appliances, the biogas stove is the commonly used appliance in households although the biogas lamps are also being adopted lately (Tumwesige et al., 2014).

Table (2): Manure Percentage available at household level fed into the biogas digester

	Dairy cattle	Local Cattle	Market swine	Breeding swine
COUNTRY	%	%	%	%
Uganda	97.5	88	47.4	18.5
Kenya	95.4	59.5	50	75
Tanzania	81.9	21.5	3.6	0.6

Source: Clemens, (2018) from https://doi.org/10.1016/j.esd.2018.05.012.

2.7. Constraints towards biogas adoption

In developing countries, more than 2 billion people depend on biomass as a source of energy particularly in households (FAO, 2019). Tata Energy Resource Institute 2002 noted that biomass provides 6% of the total primary energy supply globally and the dependence on fuel wood by households is attributed to the fact that there is accessibility and availability to wood.

The use of biogas as household energy released from AD of organic feedstock has a long history in developing countries (Dutta et al., 1997; Wang et al., 2016). However, the adoption of the technology is still low under the demand for organic wastes that has increased significantly (Ngan, 2011). Various variables are associated to the adoption of biogas and relate to a person's attitude that makes them reject or adopt a certain technology (Mwirigi, et al., 2018). Studies that were conducted in Africa (Kenya, Tanzania, Uganda, Ethiopia, Burkina Faso) and Asia (Cambodia, Bangladesh, Vietnam, India and Nepal) in 2013 being supported by SNV indicated that lack of income, inactive involvement of the private sector, lack of subsidy facilities and inactive national policies were among the variables hindering adoption of biogas technology (Ghimire, 2013). In Kenya and other studies conducted in the developing countries, level of education, income, size of farm, farm ownership and number of animals and cost were the major socio-economic factors (Mwirigi, 2009; Mwirigi et al., 2018).

Lemma et al., (2020) noted that distance to firewood sources, access to credit, distance to water sources, access to electricity and access to electronic media are the socioeconomic factors related to biogas adoption in a study conducted in Ethiopia. However, Roubík et al., (2014) noted that lack of knowledge and awareness on how to use the technologies is the main variable hindering adoption of biogas technologies.

2.8. Potential Benefits of using Biogas

Biogas energy has many benefits which can be experienced at different levels of the economy (household, local, national, and global). The benefits are valued differently depending on the county and can be categorized according to their influence on health, gender, environment, and economic (employment) (SNV, 2009).

Apart from biogas being clean and renewable energy that households in developing countries can access, biogas technology presents the following advantages (Msibi, et al., 2017)

2.8.1. Environmental benefits

Households in developing countries extensively use fuel wood which imposes effects on the forest cover. Osei (1993) noted that 54% of forest destruction is linked to fuel wood use in developing countries and 17%-25% anthropogenic greenhouse gas (GHG) emissions are linked to worldwide deforestation (Strassburg et al., 2009).

The environmental benefits of biogas are emphasized as sustainable and a justifiable alternative to fossil fuels (Cecchi, 2015). When households use biogas digesters as a source of energy instead of fuel wood, direct burning of 3 metric tons of firewood and 576 kg of dung deals away with 4.5 metric tons of CO_2 emissions to the atmosphere thus environmental protection (Katuwal et al., 2009). In addition, the impact on the quality of air is lower when the municipal wastes, agricultural and zootechnical by- products of biogas are exploited compared to when fuel wood is burnt (Domingo et al., 2015). The use of municipal wastes, agricultural and zootechnical by- products as soil fertilizers is a sustainable method which reduces the production and use of synthetic chemicals (Valerio et al., 2018).

The anaerobic by-products known as digestate or bio-slurry can be used as a source of soil fertilizer and the substrate is rich in potassium, micronutrients, nitrogen, and phosphorus (Osama, 2019). It helps to improve the soil physically, chemically, and biologically thus increasing crop yields (Surendra et al., 2014). Finally, biogas can be suitably be used as fuel in vehicles or put into the national gas grids when upgraded to biomethane (Valerio et al., 2018).

2.8.2. Social/ gender benefits

Women and children in the rural areas of developing countries spend most of their time collecting firewood and performing domestic work but because of biogas technology implementation, their workload is decreased by 50% in developing countries allowing them to have time for other activities like education and income generation among others (Garif et al., 2012 & Katuwal etal., 2009).

Waste generation being one of the problems in countries today, biogas energy is very vital in achieving or meeting the national and European regulations. It helps reduce the amount of waste and costs of their removal. it is convenient to store and can be used anytime and anywhere (Lovrenčec, 2010).

2.8.3. Economic benefits

Due to reduction on the dependence of fuel wood, there is a likeliness of increasement in savings and incomes of households when biogas technologies are adopted and installed. The women get more time to engage in other productive activities that bring in incomes in homes (Kasap et al., 2011). For the national sector, it brings about creation of jobs with meaningful potential hence increasing incomes in rural areas and increment in government revenue (Teodorita, 2008).

Biogas being produced locally and within the means of the national boundaries, it increases the country's local energy supply. The local population get employment as work in the biogas sector needs labor to collect and transport feedstock, raw materials for digester construction, manufacturing, operation, and maintenance of the technologies. It reduces on the costs involved in the removal of wastes and the amount of waste itself as these wastes are used as feedstock in the generation of biogas energy (Lovrenčec, 2010).

2.8.4. Health benefits

In rural areas of developing countries, most health issues concerning women and children are associated to the use of fuel wood because they are responsible for most of the domestic work including cooking which exposes them to unclean smoke emitted into the atmosphere (Katuwal et al, 2009). This is unlike for the case of biogas energy that provides smoke free and clean energy. Its extensive installations both on small-scale and large scale could meaningfully help in decreasing illnesses and giving time to women and children to engage in other activities that are good for their health, (Surendra et al, 2014).

The use of biogas technologies act as disposal approaches for wastes and by so doing, they help in improving hygienic situations. They help in pathogenic capacity reduction or risks through fermentation in addition to reduction of disease transmission as bio digestate does not attract vermin and flies that cause contagious diseases plus the migration of smoke that causes eye infections and respiratory problems (Energypedia, 2016).

2.9. Disadvantages of biogas energy

2.9.1. Biogas Contains Impurities

The generated biogas mixture is proper for use in biogas lamps, kitchen stoves and water boilers. However, if the mixture is used in power automobiles, the engine mental parts can be corroded with the impurities that biogas contains even after the refinement and compression. Thus, the corrosion of the metal parts can cause increment in maintenance costs (Khayal, 2019; Zemler, 2020).

2.9.2. Temperature Effect

The best temperature for bacteria to digest waste is around 37°C. However, if the weather is cold below 20°C it affects the production of biogas. Therefore, biogas digesters need heat to enable the stability of the biogas supply (Zemler, 2020).

2.9.3. Less suitable for dense metropolitan areas

Large-scale biogas plants are practical in areas where there is availability of adequate wastes or raw materials that can ease the stable production and supply of biogas. And this can be more workable in the suburb and rural areas where raw materials like animal wastes and agricultural wastes are mostly generated and accessible (Energypedia, 2016).

2.9.4. Methane impact on the climate

Methane is part of the chemical processes in the atmosphere that has been brought about by the activities humans engage such as waste accumulation on large waste disposal, cattle farming, among others. It is a contributor to the greenhouse effect and can result into increase of levels in temperature that destroy the ozone layer which helps in protection of the earth against the harmful ultraviolet radiation from the sun (Khayal, 2019). Bhardwaji et al. (2017) also said that biogas is not naturally stable because when methane gets into contact oxygen, it is flamed up and can lead to explosions.

2.9.5. Non- Efficient to use on a large-scale

Most of the biogas technologies available ease the production of biogas energy on small-scale and can meet the energy needs for small-scale purposes. However, the technologies are not efficient enough to simplify the biogas production process and make it less costly. This indicates that it's not viable for production of biogas on large scale and most governments and investors are reluctant in investing in the production of biogas although it could solve the problem of climate change (Bhardwaji et al., 2017).

2.10. Feedstock for Biogas Energy Production

There is a lot of interdependencies between feedstock and anaerobic digestion. Feedstock is any type of substrates that can be changed to methane by anaerobic bacteria and influences the rector digestion and operation. It influences the bacterial physiology a branch of biology that aims at understanding the overarching principles of cellular reproduction (Steffen et al., 1998).

Various biodegradable materials which are somewhat different in preparation and production can be used in the generation of biogas energy. All feedstock used should be sufficiently available in large quantities, efficient and must lack toxic substances for it to be considered suitable for biogas generation which helps in distinguishing of the type pf biogas produced (Green Group Energy Efficiency, 2013).

Zafar (2019) noted that the different organic materials used in biogas generation are categorized into three (3) groups: agriculture, community-based, and industrial feedstock. He noted that it is not only the availability of biogas feedstock that determine the development of biogas in different countries but also the policies that encourage its production and use.

i. Agricultural feedstock can be generated from agricultural activities and crops that produce wastes. They can be used as substrates for production of biogas and feedstock such as animal manure, energy crops, algal biomass, and crop residues are all sources of agricultural wastes (Ravindranath et al., 2005).

ii. The Community-Based Feedstock are those from Organic fraction of MSW, Sewage sludge, grass clippings/garden waste, institutional and food wastes.

iii. Industrial wastes as biogas feedstock are those generated from food/beverage processing, dairy, starch industry, sugar industry, pharmaceutical industry, cosmetic industry, biochemical industry, pulp and paper and slaughterhouse/rendering plant (Zafar, 2019).

2.10.1. Phases of Anerobic Digestion

The degradation of the organic manure undergoes four phases, and the composition of the gas depends on the digestion system and type of organic manure (Bouallagui et al., 2014).

i. Hydrolysis

This is the first step in the AD process. Organic compounds are degraded into simple form to be used by the microorganisms easily which depends on factors like surface area, size, biomass, and organic substance shape.

ii. Acidogenesis (Fermentation)

In this second step, fermentation is involved. The organic compounds are further degraded by anaerobic microbes into simpler compounds of acetic acid and volatile fatty acids.

iii. Acetogenesis

In acetogenesis, the volatile fatty acids and acetic acids are further simplified into acetate and hydrogen because they cannot be used by methanogenesis.

iv. Methanogenesis

This is the last step in AD. The methanogenic bacteria convert acetate to methane and carbon dioxide which is a vital pathway in yielding energy.

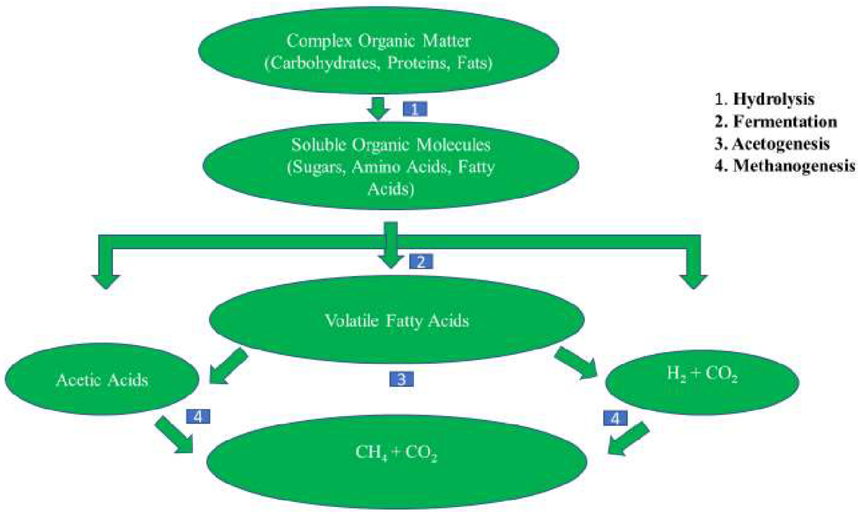


Figure (3): Illustration of stages for A.D Process adapted from Mountain Empire Community College, (2013).

2.11. Biogas digester description

A biogas digester is the heart of any biogas plant as its intake and operation are the most vital variables in the design of the whole plant (Peacock et al., 2012). It refers to an airtight chamber that enables the breakdown of biodegradable material, sludge, and black water (Tilley et al., 2014). The digester is commonly known for its ability to generate biogas and digestate as the two main products from wastes (Mattocks et al., 1984) and consists of four components: The reception tank (inlet), fermenter (rector), gas holder, and overflow tank (expansion chamber) which should be protected from chemicals, UV light, corrosive gases and insulated against extreme weather conditions (Cheng et al., 2013; Samer, 2012).

Temperature, pH, organic loading rate, hydraulic retention time and carbon to nitrogen ratio are the factors on which AD depends to biodegrade the solid feedstock which can be managed in three temperature zones; pychrophilic (10-20°C), mesophilic (20-45°C) and thermophilic (45-68°C). However, mesophilic (with an optimum at 35°C) or thermophilic (with an optimum at 55°C) is the most common (Connaughton et al., 2006).

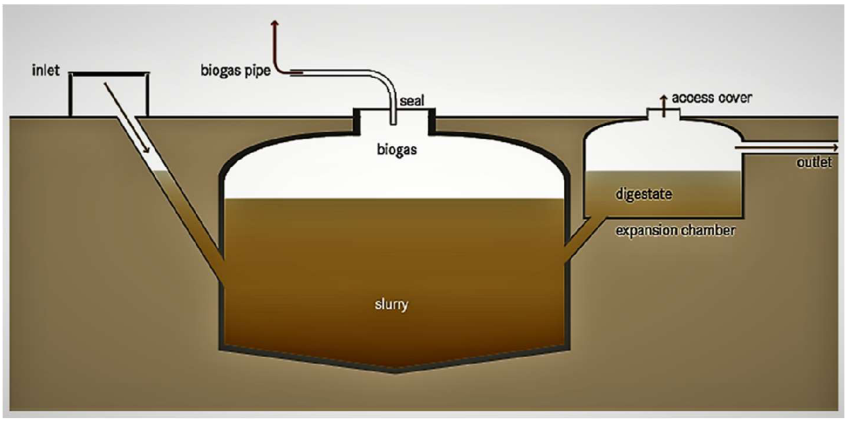


Figure (4): An illustration of Schematic biogas reactor adapted from Compendium of Sanitation Systems and Technologies, 2nd Revised edition by Tilley et al., (2014)

2.11.1. Categorization of biogas digesters

Biogas digesters can be categorized into three (Alkhalidi et al., 2019).

i. Low rate systems where feedstock flows the digester and leaves at the end of the hydraulic retention time (HRT).

ii. Passive systems where there is no control over the AD process after recovered biogas is added to an already existing waste treatment facility.

iii. High rate systems where biogas production efficiency in the digester is because of the trapped methane forming bacteria.

2.11.2. Types of biogas digesters

There are many different types of biogas plants adopted and installed for both small-scale and large-scale use in various countries. These are grouped into two which are Concerning the feed method and concerning construction. Those under the feed method are batch, continuous and semi-batch plants while those under the construction are floating drum, fixed dome, balloon, horizontal, earth-pit plants and ferrocement plants (Kossmann et al., 1999). However, Flexible balloon, fixed dome and floating drum are the most types of biogas digesters installed in Africa because they are effective, less costly and robust and human, animal and agriculture waste are the most common sources of feedstock used in the production of biogas in Africa due to the presence of agricultural, horticultural and livestock sites (Putti et al., 2014).

i. **Floating drum biogas plant**

This is sometime known as Khadi and Village Industries Commission (KVIC) and was developed in 1962. This is among the most widely accepted and used type of digester on small-scale. It has an inverted drum inserted on the digester and it is movable depending on the accumulated amount of biogas at the digester top (Singh etal., 2004).

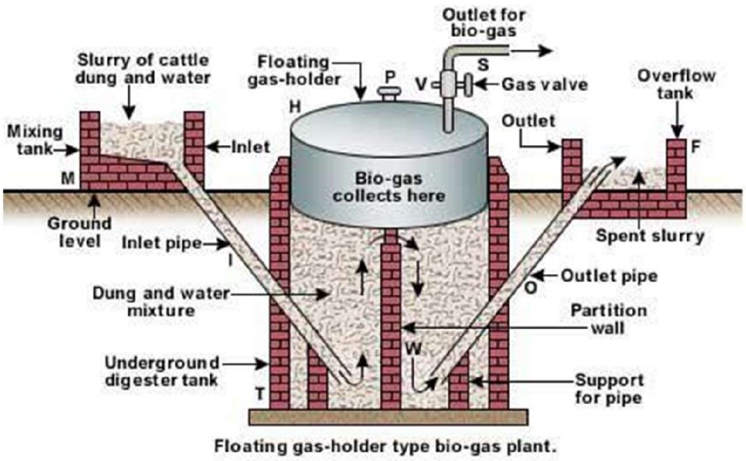


Figure (5): Floating drum biogas digester adapted from Biogas Potential in Pakistan by Saleh A., (2012)

ii. Fixed dome digester

This type of plant is suitable for cold regions and its normally built below the ground level. Its construction costs are low as it is uses locally available materials. The digester and the gas holder are not separated, and the gas is stored in the upper part of the digester as illustrated in figure 6 below (Saleh, 2012).

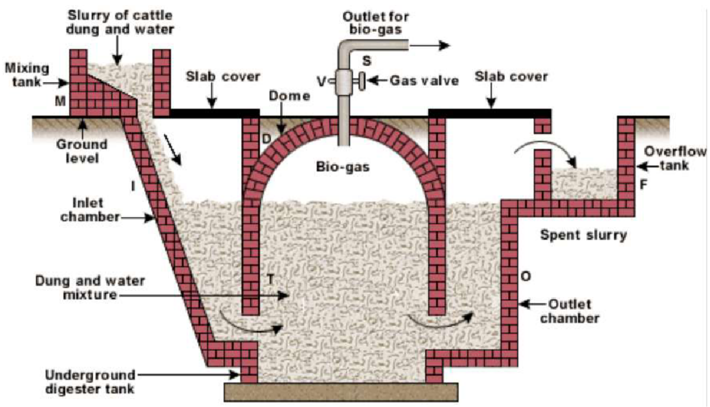


Figure (6): Fixed- dome biogas digester adapted from Biogas Potential in Pakistan by Saleh A., (2012)

iii. Balloon biogas digester

This type of biogas plant has a narrow and long tank which has an average length to width ratio of 5. It has an inlet and outlet that are above the ground and found at opposite ends. However, other parts of the digester are built underground. This type of biogas digester id easy to install and operate as compared to others (Ferrer et al., 2011).

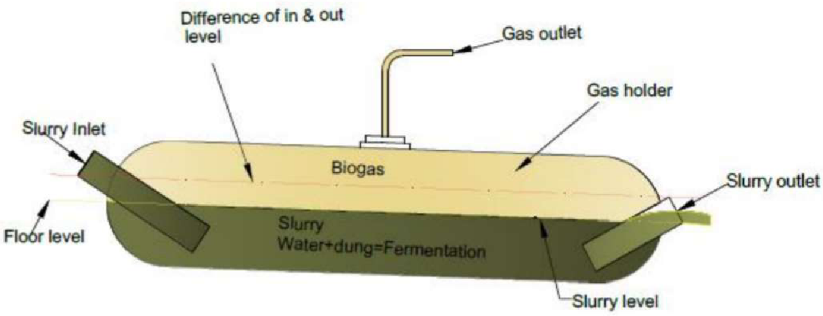


Figure (7): A Low-Cost Fixed Balloon biogas digester adapted from, "The potential of flexible balloon digesters to improve livelihoods in Uganda by Tumwesige, (2013)

2.12. Approaches used in Design and Implementation of Biogas technologies

Planning and organization play a vital role in the dissemination and implementation of any biogas technology. There is always complexity because many disciplines ranging from economics, therefore necessary to come up with an implementation plan that includes the problem analysis, aims, target group, strategy, required activities, among others (Energypedia, 2015).

2.12.1. Holistic Approach.

This kind of approach focuses on the acceptability and performance of the plant. It considers the adjustment of the existing processes for management of solid waste, improvement in usage of biogas and manure along with the addition of associated technologies. Different phases for collective performance and acceptability are involved (Kshirsagar et al., 2019).

These include:

i. Preprocessing phase that involves installation of bio-digestors focusing on the locally available resources that can be used.
ii. The main processing that focuses on the main digester design, operational feasible standards and maintenance processes that help improving the production rate of gas and fault tolerance.
iii. The post processing phase that focuses on the economic benefits from the biogas plant through effective processing of biogas and digestate.

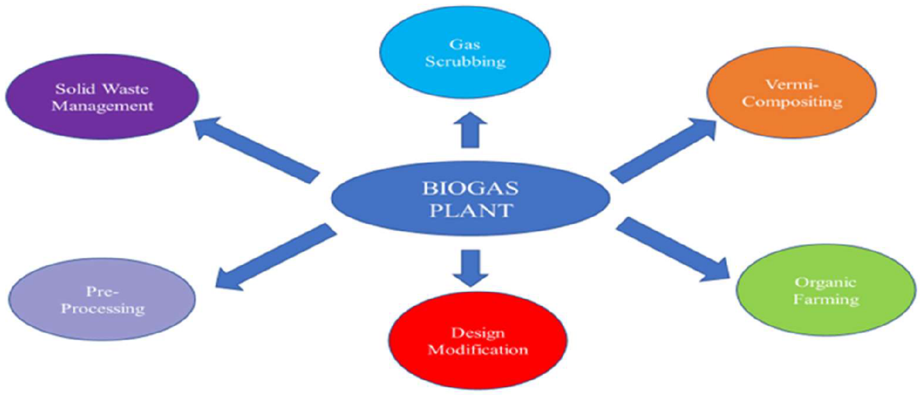


Figure (8): The Holistic Approach for biogas technology implementation adapted from Kshirsagar et al., (2019)

2.12.2. Life Cycle Approach

This approach focuses on the critical feasibility components of the biogas plant project. It is mostly used to come up with practical projects and assessment of their practicability by evaluators and stakeholders. It goes through four steps in the planning and development process of biogas plants (Scrimgeour et al, 2018).

i. Critical feasibility components decision tree stage,
ii. The development methodology stage.
iii. Viable project models stage.
iv. The implementation stage when the risks related to the plant have been lessened

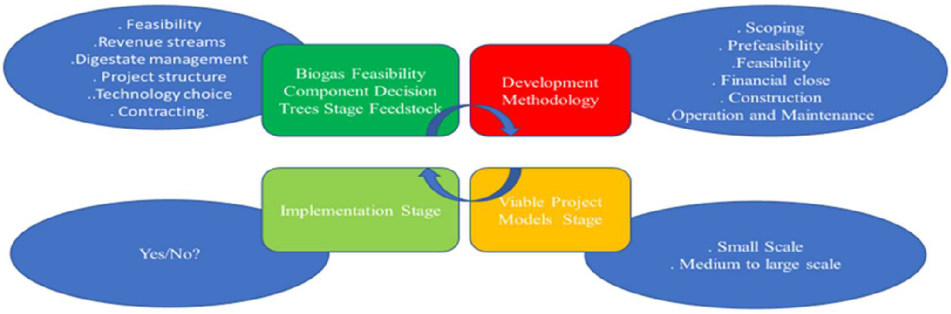


Figure (9): Biogas development Life cycle approach and what it entails adapted from Scrimgeour et al., (2018)

2.12.3. Market - Oriented Programme approach

This approach implicates different multiple stakeholders that are engaged at different stages of the value chain. It is used by two Dutch development agencies that are Netherlands Development Organization (SNV) and the Humanistic Institute for Cooperation in developing countries (HIVOS) by supporting renewable energy initiatives in various Asian and African countries and was first applies in Nepal by SNV (Hessen, 2014). SNV (2013) noted that a total of 579,306 biogas plants were installed in Asia and Africa by 2013 using the market-oriented programme approach.

2.13. SDGs and Biogas

In 2015, the United Nations adopted 17 sustainable development goals (SDGs) and 169 targets as part of a global partnership. The biogas industry is well placed to achieve nine of the SDGs – conceivably more than any other sector (WBA 2017). These nine SDGs pertain to food and energy security, well-being, gender equality, sustainable water management and sanitation, resilient regions and cities, sustainable industrialization and combating the effects of climate change. To ensure that the biogas industry is on track to meet these nine SDGs it is imperative that the biogas sector is both economically and environmentally sustainable.

Experiences from traditional biogas approaches have shown that significant government support still must make this market competitive and some of these systems are lacking sustainability in terms of high costs and environmental impact. Innovation, optimization, and implementation strategies are necessary to transform conventional digesters into more sustainable anaerobic digestion systems (IEA Bioenergy Task 37, 2018).

i. **Goal 2: Zero hunger**

A biogas plant generates biogas energy and bio slurry which can be used as an organic fertilizer. This restores the soils, increases crop yields, and improves farmers income and food security as farmers do not need to spend more money on buying of fertilizers to improve yields (Bioenergy International, 2019; WBA, 2018).

ii. **Goal 3: Good health and wellbeing**

A study carried out by Hivos in 2015 shows that there is a 36% exposure and 88% in kitchen concentration of indoor air pollution when biogas digester is installed. The levels of carbondioxide are much lower and it helps in reduction of health-related diseases caused by smoke (Bioenergy International, 2019).

iii. **Goal 5: Gender equality**

Women are vital contributors to achieving SDGs. They are primarily responsible for energy provision, collection of fuel wood and waste collection. Data on gender bias in poverty shows that 70% of the 1.3billioin people leaving in poverty are women because of the socio-cultural circumstance that women are responsible for all duties related to domestic work and childcare. This makes them work longer hours leaving no room to engage in other activities. However, if installations of biogas are made, the time will shorten and men will start getting involved in doing those responsibilities (Weldon et al., 2015).

iv. **Goal 6: Clean water and sanitation**

AD facilitate in the recycling of biosolids for energy production. In the process, it reduces odours, spread of health hazards and reduction of carbon wastewater that are left to flow into water streams by industries that could result into contamination. Hence achieving clean water and sanitation SDG (WBA, 2018).

v. **Goal 7: Affordable and clean energy**

Wastes are generated from various activities at household level. If biogas digesters are installed and these available wastes are potentially used, households will always have access to clean and affordable energy that is sustainable. In a long run, it reduces dependency on fossil fuels and fuel wood that negatively influence the environment (Bioenergy International, 2019).

vi. **Goal 9: Industry, innovation, and infrastructure**

Industries generate a lot of wastes. If the wastes are used to generate biogas energy, it leads to improvement of the social, economic and environment sustainability in addition to having a reliable energy source that cannot be depleted (WBA, 2018).

viii. **Goal 13: Climate change**

The installation of biodigester reduces greenhouse gas (GHG) emissions. It displaces fossil fuels through providing of a clean and renewable fuel biogas. It reduces methane emissions from animal waste and captures methane gas for use that could affect the ozone layer which helps in regulation of the sun rays (Bioenergy International, 2019; WBA, 2018)

viii. **Goal 15: Life on land**

Biogas energy use plays a big role in decreasing of deforestation which has a lot of impact on the life on land. It combats climate change and conserves vital species on land. In addition, the digestate produced can be reapplied to the soils which makes the soils retain its fertility and keeping the living organisms in the soils alive to act as nutrients (WBA, 2018).

3. Aims of the Thesis

The thesis aim was to investigate the use of small-scale biogas technologies vs wood-fuel and their implementation benefits in terms of the socio-economic, environmental, health and climate aspects in relation to the SDGs attainment among households in the rural areas of Iganga district, Eastern Uganda.

3.1. The specific objectives

These include:

i. To assess the level of knowledge and awareness of households on the use of biogas technology and wood fuel.
ii. To investigate whether the use of biogas technologies vis-à-vis wood fuel by households has any effect on the socio-economic, health, environment, and climate aspects.
iii. To identify the major challenges hindering the adoption of the biogas technology.

3.2. Research Questions

Therefore, regarding the above objectives the following research questions needed to be answered since energy and human development is inseparable and for Uganda to make a remarkable stride towards the achievement of biogas and SDGs in general.

i. What are the perceptions of the household users towards the use of small-scale biogas technologies vis-à-vis wood fuel?
ii. Does the use of small-scale biogas technologies vis-à-vis wood fuel have significant impact on the households in relation to the socio-economic, environment, health and climate related issues?
iii. What are the hindering factors towards the adoption of the biogas technologies amongst the households in Iganga district besides access to biogas knowledge and Technical expertize as the main factor?

4. Research Methodology

This chapter presents a systematic step that was applied the data collection and analysis process. It provides a description of the study research design, target area, target population, size, techniques, data sources, methods of data analysis, research variables and limitations

4.1. Research Design

A mixed method design was used in data collection and analysis as it is noted that "incorporation of quantitative and qualitative methods provide detailed and comprehensive data that enables the achievement of the research questions and aims" (Bryman, 2007). Figure (10) illustrates the research design that was used in the thesis.

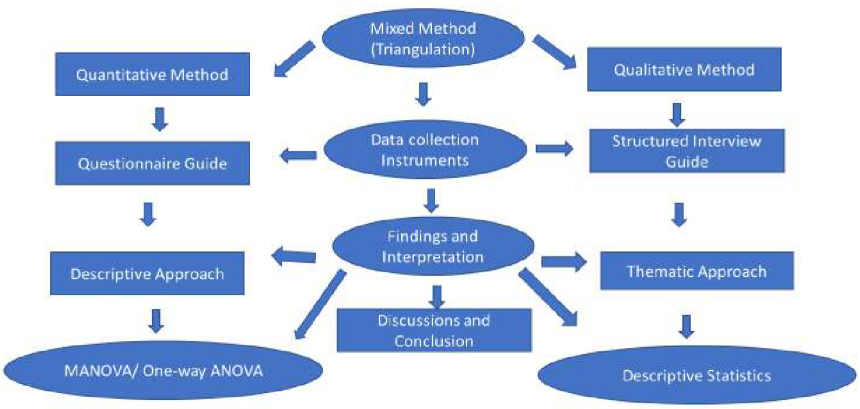


Figure (10): Thesis Research design.

4.2. Target Area

The research was conducted in Iganga district, found in the Eastern part of Uganda. It is on a land size of 1,046.75 sq. km and divided into 12 sub-counties, 66 parishes and 433 villages. It has approximately a total population of 505,405 with 102,472 households of which 17.1% (17,521) have access to electricity. 90.4% of the households practice crop growing, 65.7% engage in livestock farming while 92.5% engage in both crop and livestock farming. For waste management, 45.2% dispose-off solid waste using the registered or unregistered waste vendors and skip bins provided by the Municipal authority (UBOS, 2014)

The main target areas that were selected for the research included: Iganga municipal council with a total of 14065 households; Nakalama sub-county with 9167 households and Namungalwe sub-county with 7638 households totaling to 30,870 households (UBOS, 2014). (Please see figures 11)

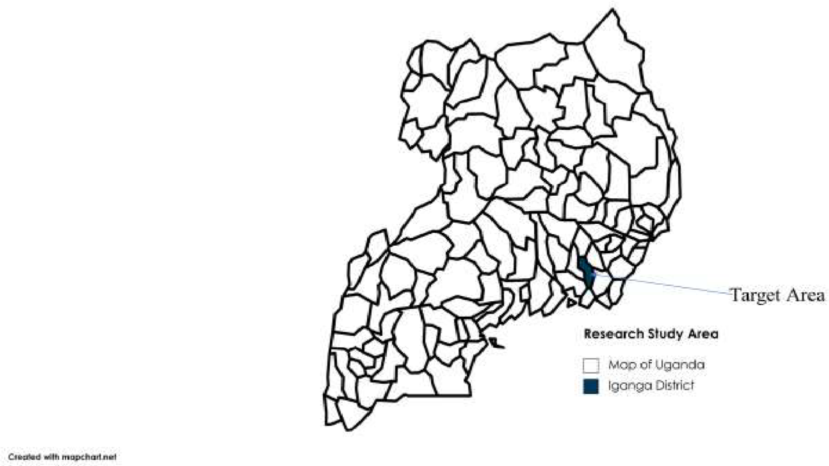


Figure 11: Thesis Study Area Map, Adapted from: Mapchart.net

4.3. Target Population, Size and Techniques.

The main study respondents in this thesis were households in addition to Local government officials and NGOs. The study consisted of 300 household, 6 Local government officials and 8 NGOs) from within the district that fully took part in the study. These were sampled using simple random, purposive and convenience sampling techniques to obtain effective data from the targeted population.

Criterions were set for the selection of the respondents, and these included:

i. Voluntary participation.
ii. Ownership of animals preferably cattle.
iii. Household engagement in any form of agriculture.
iv. Ownership of a permanent pit latrine
v. NGO's knowledgeability about biogas related matters and implementation of

community projects in line with health, environment awareness, education, and community development.

vi. Holding a well-recognized office at the district level by the local government officials.

vii. Presence of a reliable and nearby water source.

4.4. Data Sources

The thesis consisted of primary data collected from the main target group (the Households) and from the Local government officials and NGO's.

4.4.1. Primary Data Sources

The primary research data was collected through questionnaire survey and semi-structured interview guides in addition to observation of the household settings. The data collection methods consisted of both qualitative and quantitative approaches.

4.4.1.1. The Questionnaire

A total of 300 questionnaires were administered to the selected households, however a total of 262 households responded. In addition to administering questionnaire surveys, observations were made to affirm the aspects of the criteria selection.

Therefore, the apparatus for data collection of vital information consisted of 42 questions divided into three (3) sections and (4) sub- sections as illustrated in in table (3) below.

Table (3): Questionnaire Vital Information

Sub-Section	Content
Personal Information about the Household	Gender, Age, Education level, Occupation, Family Size
Basic information about biogas and the related aspects	Have biogas Digester installed, Type of Digester, Financer of the digester, Year of installation, Perception about biogas use, use of the gas, Appliances used, Feedstock used and why, Energy sources used for Cooking and lighting.

Impact of Biogas vs Wood fuel use on SDGs Achievement	Socio-Economic Assessment, Environment Assessment, Health Assessment, Variables for Adoption and Use of biogas, Policy approaches
Other Biogas Adoption Related Aspects	Advantages and disadvantages of using biogas over wood fuel, permanent pit latrine existence, agriculture activity carried out, Water source

4.4.1.2. Interview

In addition to administering questionnaires, a 30 minutes interview per participant were conducted with local government officials (Agriculture extension workers, Community Development officer, and NGOs (Africa 2000 Network Uganda, Rural Development Foundation, Health and Education Fund Uganda, UNIFA and Uganda Village project) using a structured interview guide consisting of 12 questions divided into two (2) sections that is, waste management section, and biogas and the related matters.

4.5. Methods of Data Analysis, Interpretation, and Presentation

The data was sorted, categorized, coded, and analysed by different data analysis approaches and tools. The results were presented using tables, pie charts and graphs. Microsoft Office Excel and the Statistical Package for the Social Sciences (SPSS) were adapted to analyze quantitative data.

First, descriptive statistics was used to summarize the nominal scale and some of the ordinal scale variables of the target group with information providing their means, standard deviations, frequency's and percentages and also used to answering research question one (1).

Secondly, MANOVA test was used to find out wheither the use of small-scale biogas technologies vis-à-vis wood fuel has a significant impact on the households in relation to the socio-economic, environmental, health and climate related issues and answered research question two(2). This model is a statistical analysis used in examining the effects of one or more independent variables on multiple dependent variables. This was selected because it tests whether the independent grouping variable simultaneously explains a statistically significant amount of variance in the dependent variable.

Lastly, ANOVA test was used to analyze research question three (3) that seeked to find out the factors hindering adoption of the biogas technologies amongst the households in Iganga district. This model is tests whether the means of two or more groups are significantly different from each other and checks the impact of one or more factors by comparing their samples. It was used to understand how the different groups of my variables responded to the null hypothesis for the test. If the results showed a statistically significant result, it meant that the different population are different or unequal but if it showed non-significant results, it meant that the different populations were equal.

4.6. Research Variables

Question 1

i. Perception of household users towards the use of biogas vs wood fuel.

ii. Motivating factors for biogas adoption and use.

Question 2

i. Presence of biogas in the household.

ii. Use of biogas technologies vis-à-vis wood fuel have significant impact on the households in relation to the socio-economic, environment and health.

Question 3

i. Access to biogas knowledge and technical expertise are the main variables hindering biogas adoption besides.

ii. Other Factors.

4.7. Limitations of the Thesis

These included restricted movements due to the COVID-19 lock down in the country where transportation was hiked, the quality of information collected being not sufficient as everything was done in a rush; missing data due to failure of some respondents to answer certain question; unreceptiveness of some household heads due to government failure to give support, and un-openness of the respondents,

5. Results and Discussion

This chapter presents the results on the selected variables of the study that included analysis using descriptive statistics, MANOVA and ANOVA tests.

5.1. Socio-Economic data of Households

This presented data on household heads (HHH) in terms of gender, age, education level, occupation, and family size.

5.1.1. Gender of HH heads

This was categorized into two groups (1= Male and 2=Female). Table (4) shows an average mean for all HHH gender as 1.29 where majority were male headed households accounting for 71% while minority were female headed households accounting for 29%. This high percentage may be due to the socio-economic and cultural aspect in African context where men are expected to be the heads in the family, in-addition to making decisions as they are the bread weaners. These results are in line with Mengistu et al., (2015) study results conducted in Northern Ethiopia that indicated majority of the household head biogas adopters were male headed families (90.6%) which could have been caused by cattle-head size, income, landholding and labour availability.

Table (4): Gender of HHH

	Frequency	Percent	Valid Percent	Cumulative Percent	Mean	Std. Deviation
Male	186	71	71	71	1.29	0.45
Female	76	29	29	100		
Total	**262**	**100**	**100**			

5.1.2. Age of Household Heads

Age of the household respondents were classified into four categories that were: (18-25), (26-34), (35-43) and 44 – above. The age frequency and percentage distribution of the household heads is shown in the table 5 below.

The overall average age of the respondents was observed to be 3.25 and the standard deviation of 0.760. It is evident that the respondents between ages 44-above accounted for 42.7%, those between ages 35-43 accounted for 40.8%, those between 26-34 accounted for 14.9% while those between ages 18-25 accounted for 1.5% representing the minority. These high percentages for the age brackets may be because, it is general knowledge that older people between ages (35- 43 & 44 -above) are economically active, vital in providing labor in addition to having access, ownership and control of resources. This makes them to appreciate the benefits of using biogas and bringing about capability to invest in the installation of biogas.

Table (5): Age groups of HHH

Age Bracket	Frequency	Percent	Valid Percent	Cumulative Percent	Mean	Std. Deviation
18-25	4	1.5	1.5	1.5	3.25	0.760
26-34	39	14.9	14.9	16.4		
35-43	107	40.8	40.8	57.3		
44 -Above	112	42.7	42.7			
Total	**262**	**100**	**100**			

5.1.3. Educational level of Household Head

The level literacy is considered an index of social advancement of a community and education is an influencing factor in the decision-making process. The respondents were categorized in 6 groups (illiterate, literate but no institutional education, primary, secondary, tertiary but did not graduate and tertiary & graduated. The results of the study are presented in table 6 below.

It is evident from table (6) that the overall average mean and std. deviations for the household heads were about 4.023 and 1.516 respectively. The results show that majority of the household heads completed secondary level of education accounting for 23.3% while minority (illiterate) accounted for 6.9%. The high percentages for secondary level, tertiary but did not graduate, tertiary and graduated levels of education for HHH may be due to their comprehension skills on the use of biogas and their ability to understand and value the benefits of biogas use especially connected to the socio-economic, environment and health aspects.

Table (6): Educational level of HHH

Frequency						
	Frequency	Percent	Valid Percent	Cumulative Percent	Mean	Std. Deviation
Illiterate	18	6.9	6.9	6.9	4.023	1.516
Literate but no Institutional Educ.	30	11.5	11.5	18.3		
Primary	44	16.8	16.8	35.1		
Secondary	61	23.3	23.3	58.4		
Tertiary but did not graduate	54	20.6	20.6	79		
Tertiary and graduated	55	21	21	100		
Total	**262**	**100**	**100**			

5.1.4. Occupation of HH Head

This was categorized in 6 groups (civil service, business, farmer, manual laborer, domestic worker, and others. The results show the overall average mean for the occupation variable as 2.56. The household heads that earn from the business occupation were the majority with 32.1% while the domestic workers were the minority. See table (7) below. The occupation of the HHH is a determining factor for biogas use because the installation costs for a biogas plant are high. Therefore, for a HHH with a stable and promising job, it can be in position to pay for the initial costs of biogas installation coupled with other expenses involved.

Table (7): Occupation of HHH

Frequency						
	Frequency	Percent	Valid Percent	Cumulative Percent	Mean	Std. Deviation
Civil Service	72	27.5	27.5	27.5	2.56	1.57
Business	84	32.1	32.1	59.5		
Farmer	62	23.7	23.7	83.2		
Manual laborer	8	3.1	3.1	86.3		
Domestic Worker	2	0.8	0.8	87		
Others	34	13	13	100		
Total	262	100	100			

5.1.4.1. Family Size of Household

The average mean for household family sizes was 9.10. 41 of the households had a maximum number of 5 respondents accounting for 15.6% clearly showing that they were the majority as seen in figure (12) below. One (1) of the household clearly showed that it had 22 dependents with 0.4%.

The results indicating that the majority of households have 5 dependents is a moderately large household which is sufficiently required in provision of household labor needed in biogas operation in-terms of routine maintenance. However, in contrary, a committed households wheither large or small can manage to feed a digester as the recommended requirements are just minimal.

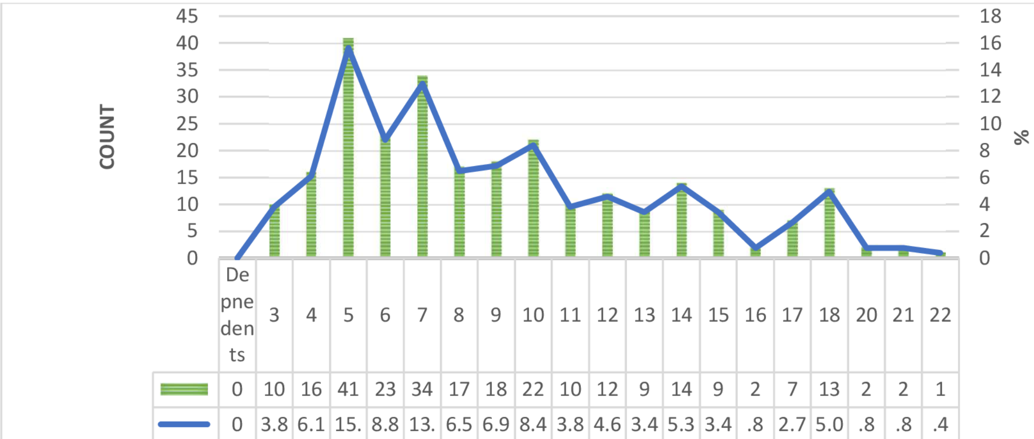


Figure (12): Family size of HH

The blue trend line in figure (12) above represents the percentage values of the different household dependent categories. The figure indicates that the majority of the households with 5 dependents had the highest percentage value of 15%. While the green line in the figure represents the frequency of dependents per household where the households with 5 dependents appeared 41 time.

5.1.5. Biogas and its related aspects

This section presents results for the following variables that contributed to the adoption and use of biogas energy.

- Whether the household had biogas installed or not taking values of 1= Yes and 2=No; type of biogas digester installed taking values of 1=fixed dome, 2=floating drum, 3=balloon and 4 = others; financer of the plant with values of 1= self-sponsored 2= NGO; 3=Government and 4=others; and year of installation

- Usage of the energy; appliances used and alternative energy source for those without biogas.
- Feedstock type used and why it is used.

Table (8) presents the independent variable "presence of biogas digester" that was used to determine whether the use of biogas vs wood fuel has a significant impact on the attainment of SDGs in the MANOVA test conducted (please see table 12, 15 & 18). The results in table 8 presents the overall mean average as 1.40. 60.3% of the respondents had biogas installed in their households while those without biogas were 39.7%.

Table (8): Frequency table for presence of biogas in household.

Descriptive Statistics								
	N	Mean	Std. Deviation	Variance	Skewness	Kurtosis	Frequency	Percent
Presence of biogas in the household	262	1.40	.490	.240	.424	-1.835	Yes = 158	60.3
							No =104	39.7
							Total = 262	100

It was found out that fixed dome accounted for 91.1% of the installed plants, balloon with 5.7% and lastly the floating drum accounting for 3.2% (see figure 13) and it clearly showed that fixed dome was commonly used in the target areas while floating drum was the least used. It was noted that the fixed dome type was the commonest because they are easier to construct, require fewer feedstock, and are easier to maintain and operate. These results are similar to Walekhwa et.al, 2014 findings where noted that the fixed dome and floating drum digester designs are the commonly used digesters in Uganda although their installation costs are high for the average households.

Different financers were involved in the installation of the digesters and NGO's accounted for 56.3%, those that were self-sponsored accounted for 39.2% while the remaining 4.4 % were installed with the help from relatives. (See figure 14) and all these were installed between year 2000-2018 with year 2011 having the highest number of plants installed and accounting for 10.6% (Please see figure 23 in the annex). It clearly showed that the NGOs have played a vital role in promoting biogas use in the area while the government had played little or no role. The different NGOs involved in financing these plants and those that were interviewed included UNIFA, Africa 2000 Network Uganda and ADEN. Walekhwa et.al., (2014) findings on economic viability of biogas energy production from family-sized digesters in Uganda, noted that there was an increase in household adoption of installed biogas technologies due to the efforts by NGOs that promoted biogas use by providing subsides for investment in addition to putting up demonstration plants.

The approaches used by NGOs in implementing projects entailed the bottom-up approach to development where needs assessment was first carried out and beneficiary needs understood while on the other hand, the government used the top-bottom approach to development which involved awareness creations after the projects had been implemented. The adopted government approach led to project failure due to different challenges related to ownership by the community and sustainability factor. In addition, inadequate funds were pointed out as one of the hinderance to biogas adoption and other renewable energies.

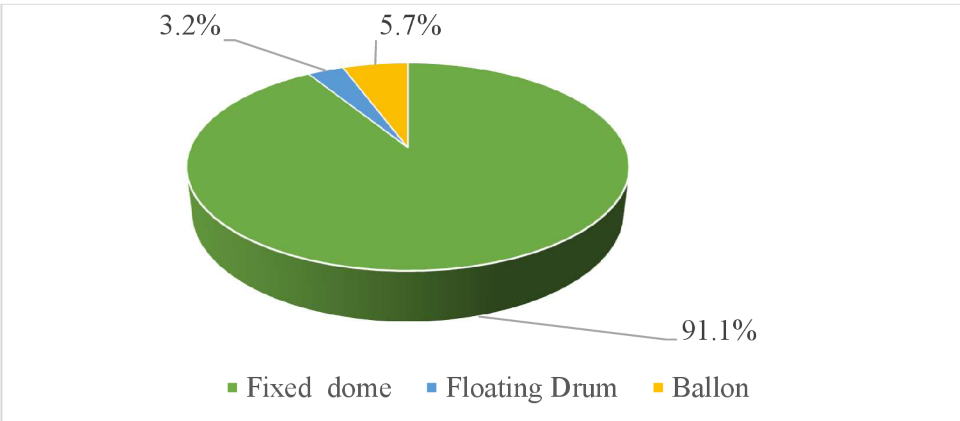


Figure (13): Biogas Digester Types Installed

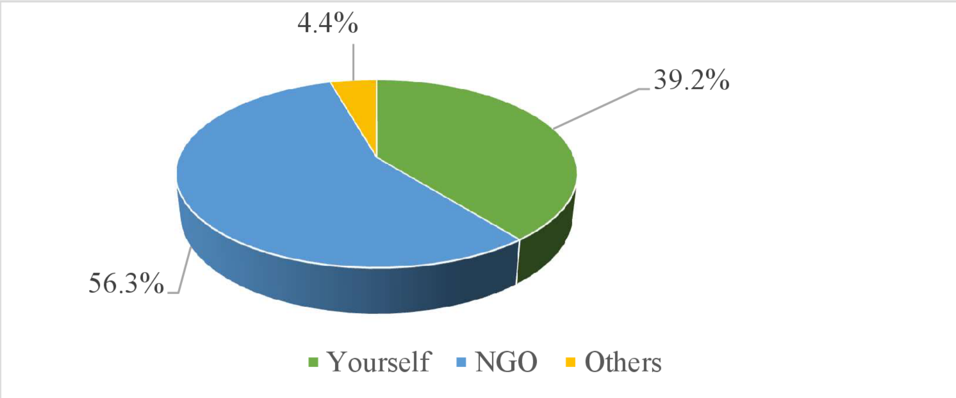


Figure (14): Financer of the Biogas Digesters

5.2. Biogas Appliances, energy usage and Alternative energy sources

Data on different biogas appliances used, the energy uses and the alternative energy sources for those without biogas is presented here.

Figure (15) presents results on different biogas appliances used by households. The data clearly showed that refrigerators with 2.6% were the least used appliances while biogas stoves had 53% being the mainly used appliances. This was in line with Tumwesige et al., (2014) findings where it was noted that biogas stove was the commonly used appliance in households although the biogas lamps are also being adopted lately. The results in figure (16) showed that biogas was mostly used for cooking accounting for 59.4%, followed by lighting with a percentage of 37.1%. This data supports the data findings presented by figure (15) that showed that biogas stoves and lamps were the main appliances used because these go hand in hand.

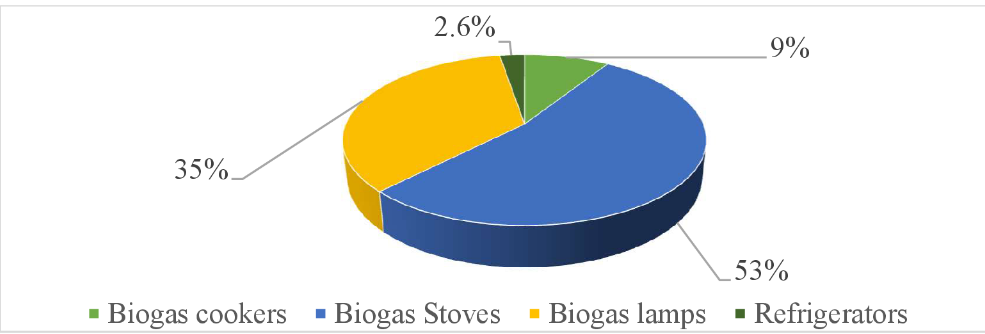


Figure (15): Biogas appliances used

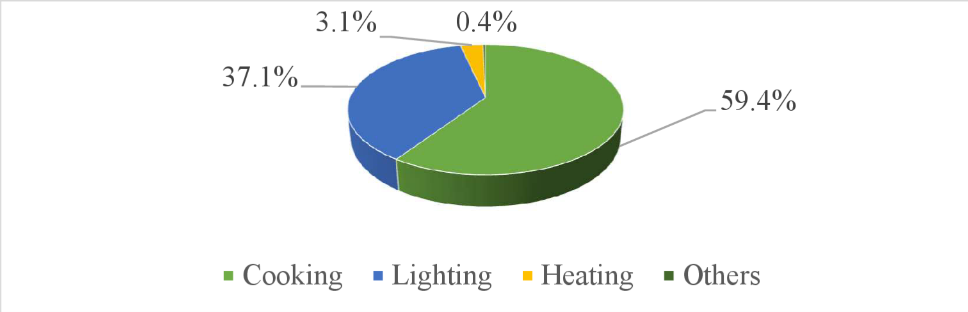


Figure (16): What Biogas is used for

The alternative sources of energy used by the 39.7% of the households (see Table, 8) that do not use biogas was biomass (wood fuel) with 41.3% followed by hydro power (32.7%), solar system (20.2%) and lastly fuel generators and other sources of energy (see_figure 23 in the annex). This relate to the information collected through interviews where it was noted that biomass, hydropower and solar were the most used energy sources in the area. Biomass is the major alternative source of energy because its locally accessible, cheap and easy to use compared to other sources of energy. In addition, these results provide supporting evidence to the finding of IRENA, (2017) where it was noted that in East Africa, biomass is majorly the primary energy source in the rural areas and is mainly used for cooking. Although biomass is said to be the main alternative energy source, the results indicate that hydropower in addition to solar are used as a supplement although the challenges that limit their use were high installation and maintenance costs for both solar and hydropower, poor service delivery in addition to availability of wood fuel that limits consumption of other energy sources (SE4ALL Initiative, 2013).

5.2.1. Feedstock and Agriculture Activity carried out by Households

5.2.1.1. Feedstock

Respondents were asked to select which feedstock type was commonly used by the household in biogas generation which included crop, animal, human and kitchen wastes that took values of 1, 2, 3 and 4, respectively. This was an important factor in understanding the different kinds of waste generated and used by households.

The results indicated that the households used two types of feedstock (see figure, 17). Animal waste accounted for 84.6% and human waste accounted for 15.4%. It was found out that animal waste was the main feedstock used because it was readily available and accessible from the household settings and from the neighbors at a low cost due to ownership of animals while human waste was perceived to be unclean and dirty for biogas generation. This is in line with Oluka, (2013) findings on the commonest type of feedstock used in Uganda that said that animal and human wastes are the commonly used feedstock for biogas generation.

Figure (17): Feedstock Type used

In relation to variable in figure (19) different reasons were sought to find out why the feedstock was used and put on a Likert-scale of 1 to 4 where 1=It is easy to prepare, 2 =It is readily available, 3 = It is cheaper and 4 = Others. The results indicated that that the feedstock is cheap with 40.4%, followed by readily available in the area with 33.5%. (please see figure (24) in the annex). Contrary to variable in figure (17), the interview data collected indicated that kitchen and agriculture waste were the commonly collected waste and these were from markets and restaurants around the areas. The interviewees pointed out that the district gazetted temporary dumping sites where the waste is dumped and collected by pick-up trucks daily and taken to temporary landfills in the district.

5.2.1.2. Agriculture Activity carried out by Households

Following the criterion set, it was found out that all participants had a permanent pit latrine. The results indicated that majority of them engaged in at least one or more agriculture activity accounting for 83.8% while 10.4% were not (Please see table 22) in the Annex). Figure (18) showed that majority of the households carry out mixed farming which involves crop cultivation, animal and poultry rearing accounting for 56.5%. While the rest of the households engage solely in poultry rearing accounting for 16.7%, followed by crop cultivation with 15% and lasty few of them in animal production with 10.7%.

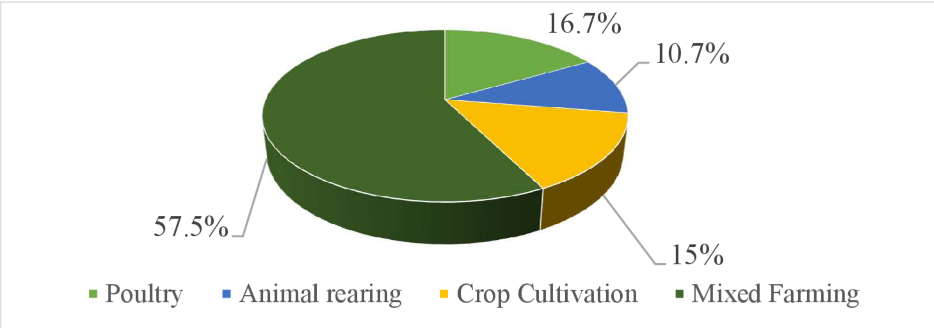


Figure (18): Agriculture Activity Carried out by Household

These agriculture activities are mainly for both subsistence and commercial purposes in (figure19) accounting for 63.2% while 30.3% and 6% is accounted for subsistence (home consumption) and commercial purposes only. This supports the results in figure (18) above that indicated that majority of households practice mixed farming.

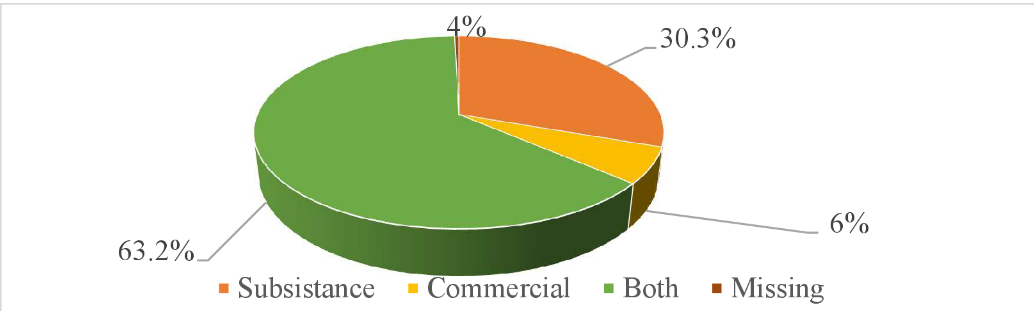


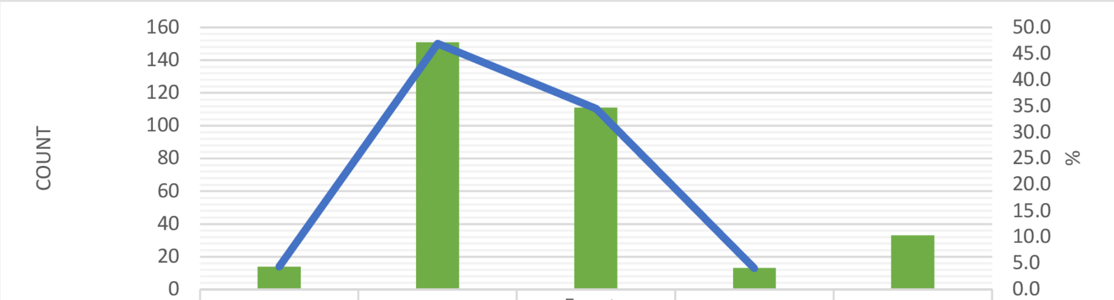
Figure (19): Use of Agriculture Activity

The percentages in Figure 18 and 19 may be due to the reason that the biggest portion of the households are small-scale farmers who have little access to the market in addition little access to resources that can enable them to mixed farming which is partially for home and market consumption.

5.3. Perception of Households towards biogas plants vs wood fuel use

This presents results on the households perception on the use of biogas technology vs wood fuel in addition to supporting reasons that motivated household to adopt biogas use.

The results presented in figure (21) showed that majority (46.9%) of them perceived generated biogas as being a clean energy source which is smoke free, followed by the digesters being easy to maintain and operate as long as the feeding of the digester's is concerned where the wastes are available, accounting to 34.5%, few perceived that its installation costs are low at 4.3% while those that had other reasons and missing data accounting to 4% and 10.2% respectively. These results were in line with Chelagat, (2016) results that observed that when you use biogas, waste is readily available, cheap in addition to the energy produced being clean. This could mean that the household users of biogas are knowledgeable and have a positive attitude towards biogas use but there are other factors that hinder their adoption .



	Low cost installation	Generates Clean gas,	Easy to maintain and operate.	Others (specify)	Missing
Frequency	14	151	111	13	33
Percent	4.3	46.9	34.5	4.0	

Figure (20): Perception of Household Users Towards the Use of Biogas

4.2.1 Motivating factors leading to biogas adoption

These variables provided reasons that supported the respondents views in figure 21 connected to the perception of household users towards biogas.

Table (9) presents results for factors that motivate household to adopt biogas. The results indicated that biogas "being smoke free" is the most vital factor that motivates them to use it with average mean of 5.84 while the "subsides given by the government" with an average mean of 1.35, being the least factor that does not motivates them since the government has little or no role in supporting the community towards the use of energy.

Table (9): Mean and Std. Deviation for Motivating factors that lead to biogas adoption

Descriptive Statistics							
	N	Range	Mean	Std. Deviation	Variance	Skewness	Kurtosis
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic
Easy to Use	262	4	2.49	.731	.534	.248	.404
Subsides given by the government	262	5	1.35	.950	.902	3.123	9.720
Women and Children get time to engage in other developmental activities.	262	4	4.46	.791	.625	-.788	1.106
Saves money	262	4	2.46	.824	.679	.206	-.077
Its smoke free	262	2	5.84	.384	.148	-2.301	4.494
Time spent on cooking is reduced	262	4	4.35	.879	.773	-.340	.411
Valid N (listwise)	262						

From the evidence provided by study findings in table (9), they provide supporting evidence to the study results of a survey carried out in Uganda, Tanzania and Kenya on better understanding the decision process on biogas adoption by Ghimire (2013) where it was noted that using biogas produces clean energy, convenient and saves time and money. As a matter of fact, in the African culture all domestic related chores like (cooking) is a women s role. Therefore, the responses of the household heads imply that they are gender sensitive because most of the significant results lead to improvement of the wellbeing of women and in a long run, lead to SDG attainment.

5.4. The results of Multivariate Analysis of Variance Test

The MANOVA test was used to analyze wheither the use of small-scale biogas technologies vis-à-vis wood fuel has a significant impact on the households in relation to the socio-economic, environment, health and climate related issues?

The independent variable used in this analysis was "Wheither a household has biogas installed or not" (please see Table, (8). The dependent variables were grouped into three categories (Socio-economic benefits, Health Benefits and Environment benefits) that were ranked as 1= lowest benefit and 8 = highest benefit. The socio-economic category had eight (8) dependent variables while health and environment had three (3) dependent variables each.

5.4.1. Socio-economic Assessment

i. Table (10), the Box's Test of Equality of Covariance checks the assumption of homogeneity of covariance across the groups using an alpha=.01 as a criterion.

The results of the analysis that are presented in the table below, suggested that for the data, Box's M (37.197) was non - significant as p=.473.

The results show there was a no significant differences between covariances matrices as the covariance matrices between of the dependent variables were assumed to be equal and the homogeneity assumption was not violated. This means using biogas in households as a significant impact on the attainment of SDGs and therefore, MANOVA test can be performed to test wheither the vector of means of groups were from the same sampling distribution or not.

T able (10): Box's Test of Equality of Covariance for socio-economic benefits

Box's Test of Equality of Covariance Matrices[a]	
Box's M	**37.197**
F	0.998
df1	36.000
df2	164867.998
Sig.	**.473**

ii. Table (11), Levene's Test of Equality of Error Variances tests the assumption of MANOVA and ANOVA that the variances of each variable are equal across the groups.

The results of the analysis indicated that the assumption for between-group homogeneity of variance across the independent variable for all dependent variables was met as p = (0.39; 0.78; 0.62; 0.29; 0.52; 0.45; 0.39 and 0.77) was greater than a=.05. Meaning that the assumption was not violated. The results showed that when biogas is used, "the time spent in cooking is reduced with (F= 0.78)" as the highest mean difference followed by "Use of bio slurry from biogas increases crop yields with (F= 0.77), and "women and children get time to engage in education and productive activities with (F=0.62) as the major socio-economic benefits of using biogas in households.

The thesis results in table (11) below are in line with the studies made by Garif et al., (2012) and Kasap et al., (2011) who noted that women and children in the rural areas spend most of their time collecting firewood and performing domestic work, but when biogas is used, their workload is decreased by 50% and they get more time to engage in other productive activities.

Table (11): Levene's Test of Equality of Error Variances[a] for socio-economic benefits

Levene's Test of Equality of Error Variances[a]				
	F	**df1**	**df2**	**Sig.**
Reduces on the time spent in collection of firewood	0.75	1	260	**0.39**
Time spent in cooking is reduced	0.08	1	260	**0.78**
Women and children get time to engage in education and productive activities	0.24	1	260	**0.62**
Creates employment	1.13	1	260	**0.29**
Increases household savings and incomes.	0.42	1	260	**0.52**
Reduces costs of waste removal	0.58	1	260	**0.45**
Increases energy supply	0.73	1	260	**0.39**
Use of bio slurry from biogas increases crop yields	0.09	1	260	**0.77**

iii. Table (12), the Multivariate analysis test is the main table of results. When looking for if there are significant differences between the groups of dependent variables in a linear arrangement, the recommended test to use is the Wilks' Lambda because it is robust due to the large sample size of my study. Using an alpha level of .05, the group effects for the independent variable are of interest because they tell us wheither or not it differs along the eight dimensions of the dependent variables (socio-economic benefits) of using biogas energy.

As demonstrated in table 13, the column of interest is that with the significance values of the F-ratios. The significance level for the independent variable "Presence of biogas in the household" result is 0.71 which is greater than the alpha (.05).

Therefore, it shows that there is no difference between the household responses meaning the groups do not differ and therefore, 'using biogas vs wood-fuel has a significant effect on the dependent variables (socio-economic benefits) towards the attainment of the SDGs.' is retained.

Table (12): The Multivariate Test effect of presence of biogas in household on Socio-Economic benefits

Multivariate Tests[a]							
Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	1.00	**104429.756[b]**	8.00	253.00	**0.00**	1.00
	Wilks' Lambda	0.00	**104429.756[b]**	8.00	253.00	**0.00**	1.00
	Hotelling's Trace	3302.127	**104429.756[b]**	8.00	253.00	**0.00**	1.00
	Roy's Largest Root	3302.127	**104429.756[b]**	8.00	253.00	**0.00**	1.00
Presence of biogas in the household	Pillai's Trace	0.02	**.673[b]**	8.00	253.00	**0.71**	0.02
	Wilks' Lambda	0.98	**.673[b]**	8.00	253.00	**0.71**	0.02
	Hotelling's Trace	0.02	**.673[b]**	8.00	253.00	**0.71**	0.02
	Roy's Largest Root	0.02	**.673[b]**	8.00	253.00	**0.71**	

5.4.2. Health Assessment

i. Table (13), the Box's Test of Equality of Covariance results indicated that the data, Box's M (27.74) was significant as p=0.00.

The results show there was a significant difference between covariances matrices as the covariance matrices between of the dependent variables were not equal and the homogeneity assumption was violated.

Table (13): The Box's Test of Equality of Covariance.

Box's Test of Equality of Covariance Matrices[a]	
Box's M	**27.74**
F	4.56
df1	6.00
df2	327033.35
Sig.	**0.00**

ii. Table(14): Levene's Test of Equality of Error Variances indicated that the assumption for between-group homogeneity of variance across independent variable (presence of biogas in the household) for all dependent variables was met as p=(0.98; 0.42 and 0.70) was greater than a=.05. This means that all the three dependent variables were non-significant indicating that the assumption of equal variances across groups was not violated.

Table (14): Levene's Test of Equality of Error Variances

Levene's Test of Equality of Error Variances[a]				
	F	**df1**	**df2**	**Sig.**
Increases on life expectancy	0.00	1	260	**0.98**
Reduces on eye and respiratory infections caused by unclean smoke	0.66	1	260	**0.42**
Serves as a method of waste disposal and sewage	0.15	1	260	**0.70**

iii. Table (15) shows the effects of the independent variable (have biogas installed) along the three dimensions of the dependent variables (health benefits) of using Biogas energy. The column with the significance values for the F-ratios indicated that all tests are not significant as p=0.56 is greater than a=.05. The results show that the groups do not differ in terms of the Health benefits (dependent variables) and the null hypothesis is retained. Meaning, using biogas vs wood-fuel has a significant effect on the Health benefits towards the attainment of the SDGs.

In analysis on biogas digest by GTZ (2018), they noted that in-order to estimate biogas use impact on the health sector, responses were assessed on the individual and society level. There findings indicated that when people use biogas, it increases life expectancy in addition to serving as a waste and sewage disposal method.

Therefore, when there is improvement in the household hygiene environment, there is an increment in savings, and labor productivity that in one way or another contributes to the wellbeing of the people.

Table (15): Multivariate Test effect of presence of biogas in household on Health benefits

Multivariate Tests[a]							
Effect		**Value**	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Presence of biogas in the household	Pillai's Trace	0.01	.696[b]	3.00	258.00	**0.56**	0.01
	Wilks' Lambda	0.99	.696[b]	3.00	258.00	**0.56**	0.01
	Hotelling's Trace	0.01	.696[b]	3.00	258.00	**0.56**	0.01
	Roy's Largest Root	0.01	.696[b]	3.00	258.00	**0.56**	0.01

5.4.3. Environment Assessment

i. Table (16) presents descriptive statistics generated by SPSS. The results show a difference in the mean scores for all dependent variables. In particular, the data analysis of all the mean scores where Means (2.85, 1.38 and 1.77) reach significance with standard deviations (0.41, 0.56 and 0.60).

Table (16): Descriptive Statistics

Descriptive Statistics				
Presence of biogas in the household		**Mean**	**Std. Deviation**	**N**
Reduces on deforestation	Yes	2.86	0.40	158
	No	2.84	0.42	104
	Total	2.85	0.41	262
Reduces on air pollution	Yes	1.38	0.56	158
	No	1.38	0.56	104
	Total	1.38	0.56	262
Reduces on carbon emission in the household environment	Yes	1.76	0.59	158
	No	1.79	0.62	104
	Total	1.77	0.60	262

ii. Table (17): The Levene's test table indicated that the assumption for between group homogeneity of variance across the independent variable for all dependent variables at each condition of significance values greater than a=.05.

The results indicated that the assumption for between-group homogeneity of variance across the independent variable (presence of biogas in the household) for all dependent variables was met as p=(0.38; 0.94 and 0.82) was greater than a=.05. Meaning that the assumption was not violated.

These results concede with Paolini et.al., (2018) study where they talked about the impact of biogas production on climate and atmosphere. It was indicated that using biogas in households contributes to the protection of climate change. In addition, the biogas analysis on biogas digest by GTZ (2018) indicated that with anerobic digestion, biogas energy is produced which has a vital positive climate effect. It helps on the reduction of CO_2-emmisions that is caused by deforestation in-addition to capturing methane emissions. Therefore, production of biogas through anaerobic digestion is a more sustainable approach to attaining a cleaner energy source that helps in mitigating the negative effects of using biomass hence attaining some of the SDGs.

Table (17): Levene's Test of Equality of Error Variances

Levene's Test of Equality of Error Variances[a]				
	F	**df1**	**df2**	**Sig.**
Reduces on deforestation	0.77	1	260	**0.38**
Reduces on air pollution	0.01	1	260	**0.94**
Reduces on carbon emission in the household environment	0.05	1	260	**0.82**

iii. Table (18) shows the effects of the independent variable (presence of biogas in the household) along the three dimensions of the dependent variables (environment benefits) of using Biogas energy. The results in the column of interest having the significance values for the F-ratios indicated that all tests are not significant as p = 0.88 was greater than a=.05. This shows that the groups do not differ and therefore, the null hypothesis is retained. Meaning, using biogas vs wood-fuel has a significant effect on the dependent variables (environment benefits) towards the attainment of the SDGs.

Janas et.al (2018) noted that atmospheric pollutant emission is the main issue of focus regarding biogas production. Gases like methane and carbon dioxide generate greenhouse effect and can be used to assess the impact of biogas industry on climate change. It is

Therefore, anaerobic digestion reduces on the emission of greenhouse gases that in-turn help in mitigating some of the environment related issues hence attaining some of the SDGs.

Table (18): Multivariate Tests effect of presence of biogas in household towards Environment Benefits

Multivariate Tests[a]							
Effect		**Value**	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Intercept	Pillai's Trace	0.99	8534.743[b]	2.00	259.00	**0.00**	0.99
	Wilks' Lambda	0.01	8534.743[b]	2.00	259.00	**0.00**	0.99
	Hotelling's Trace	65.91	8534.743[b]	2.00	259.00	**0.00**	0.99
	Roy's Largest Root	65.91	8534.743[b]	2.00	259.00	**0.00**	0.99
Presence of biogas in the household	Pillai's Trace	0.00	.129[b]	2.00	259.00	**0.88**	0.00
	Wilks' Lambda	1.00	.129[b]	2.00	259.00	**0.88**	0.00
	Hotelling's Trace	0.00	.129[b]	2.00	259.00	**0.88**	0.00
	Roy's Largest Root	0.00	.129[b]	2.00	259.00	**0.88**	0.00

5.5. The results of One -Way Analysis of Variance (ANOVA) Test

The ANOVA test was used to analyze the hindering factors towards the adoption of the biogas technologies amongst the households in Iganga district besides access to biogas knowledge and Technical expertise as the main factor. The independent variable was categorized into four group responses put on a Likert scale of 1=Strongly Agree, 2=Agree, 3=Disagree and 4=Strongly Disagree. The dependent (response) variables were six and ranked as 1= lowest benefit and 6= highest benefit.

5.5.1. Access to knowledge and technical expertise.

A descriptive statistic test was conducted to assess wheither access to biogas knowledge and technical expertise are the main variables hindering adoption of biogas besides other factors.

The result findings are presented in figure (21) and showed that majority (45%) of the households strongly agreed while on the other hand, 7.3% strongly disagreed. This is because, having knowledge about biogas broadens people perceptive on its benefits and the various issues related to its use.

These provide supporting evidence to Chelagat, (2016) findings in his study on the attitudes influencing adoption of biogas fuel among workers and learners that stated that limited availability of well-trained biogas technicians was a barrier that attributed to low biogas adoption status coupled with Eghosa et.al, (2020) that indicated that little awareness of the technology hinders biogas adoption and dissemination.

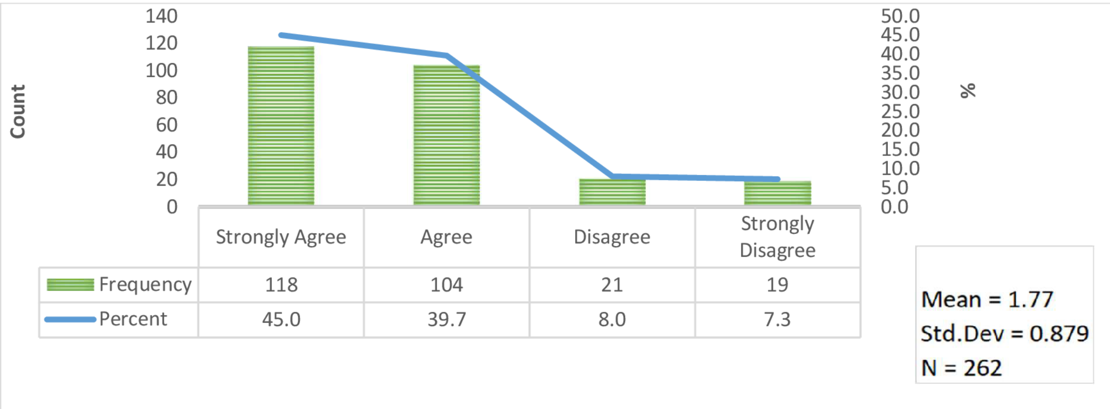


Figure (21): Access to Biogas Knowledge and Technical Expertise

5.5.2. Access to biogas knowledge and technical expertise (Independent variable) effect on the Dependent Variables

i. Table (19) presents descriptive statistics generated by SPSS for the for dependent variables of "access to biogas knowledge and technical expertise" that showed a difference in the mean scores for all dependent variables. In particular, the mean scores (3.62, 3.79, 4.29, 5. 64, 1.22 and 1.94) reached significance at an alpha of .05.

Dependent variable (Initial investment too high) had the highest mean score (5.64) while dependent variable (Biogas is dangerous) had the lowest mean score across all the dependent variables. This meant that besides the main factor (Access to biogas knowledge and technical expertise), the initial investments that are incurred in when installing the plant also has an a significant effect in hindering biogas adoption, followed by the firewood being readily available with the mean (4.29), in addition to having no government support with mean score (3.79) among others. More is visible in the Table (19) below.

The study results that showed significant difference between the means do not contradict with the study results that were supported by SNV, (2013) in different East African countries (Uganda, Kenya and Tanzania) and Asia (India, Nepal, Cambodia, Vietnam) that stated that lack of income to incur in when installing the plant; lack of subsidy facilities and inactive government policies are among the main factors that hinder biogas adoption in these countries.

Table (19): Effect of the Independent variable along Dependent Variables.

Descriptive Statistics							
						95% Confidence Interval for Mean	
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound
No access to sufficient supply waste	Strongly Agree	118	3.54	.844	.078	3.39	3.70
	"Agree "	104	3.53	.653	.064	3.40	3.66
	Disagree	21	4.10	.700	.153	3.78	4.41
	Strongly Disagree	19	4.05	.848	.195	3.64	4.46
	Total	262	**3.62**	.783	.048	3.52	3.71
No sufficient government support	Strongly Agree	118	4.31	1.019	.094	4.13	4.50
	"Agree "	104	4.15	1.147	.112	3.93	4.38
	Disagree	21	3.90	1.044	.228	3.43	4.38
	Strongly Disagree	19	**3.79**	1.134	.260	3.24	4.34
	Total	262	4.18	1.087	.067	4.05	4.31
Firewood readily available	Strongly Agree	118	4.25	1.029	.095	4.06	4.43
	"Agree "	104	4.42	1.002	.098	4.23	4.62
	Disagree	21	3.95	.921	.201	3.53	4.37
	Strongly Disagree	19	4.21	.918	.211	3.77	4.65
	Total	262	**4.29**	1.006	.062	4.17	4.41

Initial investment too high	Strongly Agree	118	5.58	1.041	.096	5.39	5.77
	"Agree "	104	5.56	1.003	.098	5.36	5.75
	Disagree	21	5.95	.218	.048	5.85	6.05
	Strongly Disagree	19	5.84	.501	.115	5.60	6.08
	Total	262	**5.62**	.959	.059	5.50	5.73
Biogas is dangerous	Strongly Agree	118	1.19	.476	.044	1.11	1.28
	"Agree "	104	1.22	.461	.045	1.13	1.31
	Disagree	21	1.38	.498	.109	1.15	1.61
	Strongly Disagree	19	1.21	.535	.123	.95	1.47
	Total	262	1.22	.476	.029	1.16	1.28
Expensive than other sources of energy	Strongly Agree	118	2.02	.570	.052	1.91	2.12
	"Agree "	104	1.93	.627	.062	1.81	2.05
	Disagree	21	1.62	.498	.109	1.39	1.85
	Strongly Disagree	19	2.05	.524	.120	1.80	2.31
	Total	262	1.95	.592	.037	1.88	2.03

ii. Table (20), Test of Homogeneity of Variance provides the Levene's to check the assumption that variances of the six groups are equal (not significantly different). The results indicate that the Leven's test for "No sufficient government support" with f(3,258)=0.66, p=0.58 at an a=.05; "Firewood readily available" f(3,258)=0.49, p=0.69 at an a=.05; "Biogas is dangerous" f(3,258)= 1.24, p=0.29 at an a=0.05; and "Expensive than other sources of energy" f(3,258)=1.39, p=1.39 at an a=0.25 is not significant. Thus, the assumption of homogeneity of variance was met meaning that it was not violated.

However, for variables "No access to sufficient supply waste" and "Initial investment too high" with f(3,258)=2.99,p=0.03 at an alpha=.05 and f(3,258)=5.03, p=0.00 at an alpha=.05 showed significant difference between groups. Thus, the assumption of homogeneity of variance was not met meaning it was violated.

Therefore, on average, there is no significant difference between the variables and ANOVA test can be considered robust.

Table (20): Test of Homogeneity of Variance

Test of Homogeneity of Variances				
	Levene Statistic	**df1**	**df2**	**Sig.**
No access to sufficient supply waste	2.99	3	258	0.03
No sufficient government support	0.66	3	258	0.58
Firewood readily available	0.49	3	258	0.69
Initial investment too high	5.03	3	258	0.00
Biogas is dangerous	1.24	3	258	0.29
Expensive than other sources of energy	1.39	3	258	0.25

iii. In table 21, the F ratios (5.66; 1.90; 1.52; 1.42; 0.91 and 2.97) for all the variables reach significance. However, their p- values (0.00; 0.13; 0.21; 0.24; 0.44 and 0.03) at a=.05 indicate that some have a statistically significance between the means while others showed no statistical significance between means.

The variables that showed a statistically significant difference between the means included "No access to sufficient supply waste (F = 5.66 & P = 0.00)" and "Expensive than other sources of energy (F = 2.97 & P =0.03)" and these cannot prove that the research hypothesis is correct. Meaning that the results provide support that the research hypothesis results occurred by chance and it is unlikely that the null hypothesis is true, hence rejecting it. These significant results could be because of the study area potentiality in biogas adoption as these two variables could not be a problem in hindering the adoption rates. The area has got various available and accessible feedstock got from either neighbourhood at a cheaper price and or even the various agriculture activities the household's engage in.

On the other hand, the variables that showed no statistically significant difference between the means included "No sufficient government support with (F = 1.90 & P = 0.13)", "Firewood readily available (F =1.52 & P = 0.21)", "Initial investment too high (F = 1.42 & P = 0.24)", and "Biogas is dangerous (F = 0.91 & P=0.44)". This indicates stronger evidence for the research null hypothesis and therefore, the null hypothesis is retained.

Table (21): One-Way ANOVA Test

ANOVA						
		Sum of Squares	**Df**	**Mean Square**	**F**	**Sig.**
No access to sufficient supply waste	Between Groups	9.874	3	3.29	5.66	0.00
	Within Groups	149.958	258	0.58		
	Total	159.832	261			
No sufficient government support	Between Groups	6.665	3	2.22	1.90	0.13
	Within Groups	301.904	258	1.17		
	Total	308.569	261			
Firewood readily available	Between Groups	4.586	3	1.53	1.52	0.21
	Within Groups	259.368	258	1.01		
	Total	263.954	261			
Initial investment too high	Between Groups	3.886	3	1.30	1.42	0.24
	Within Groups	235.946	258	0.91		
	Total	239.832	261			
Biogas is dangerous	Between Groups	0.620	3	0.21	0.91	0.44
	Within Groups	58.541	258	0.23		
	Total	59.160	261			
Expensive than other sources of energy	Between Groups	3.056	3	1.02	2.97	0.03
	Within Groups	88.395	258	0.34		
	Total	91.450	261			

Variable "biogas is dangerous" is among those that was expected to show a statistically significant difference between means, however it didn't. This is due to the fact that household users have myths towards the utilization of human excreta in generation of biogas energy as it is considered dirty and perceived to be unfit for cooking hence their stigmatization in the study area and the country at large.

One of the interviewees said: "*Sincerely speaking, we consider human excrete as "BUBI". "So, how do you expect me to use it for cooking. I would rather use wood fuel* *because it's up to me to select what type of tree I want to use*". In my language (Lusoga), traditionally human excrete is referred to by various words among which are, "*Amazi, Kadingo, Obubi, Empitambi*, and *Kazambi* but it is often called "*Pupu*" by the elites. Therefore, depending on the respondents thinking, the concept of using biogas energy from human excrete for cooking is still hardly imaginable. Hence there is a need for further sensitizing the masses about what biogas entails.

6. Conclusions

This study examined the use of small-scale biogas technologies vis-à-vis wood-fuel and their implementation benefits in terms of the socio-economic, environmental, health and climate aspects in relation to SDGs attainment among households in the rural areas of Iganga district, Eastern Uganda.

The study among household indicated that they mainly engage in a mixed type of farming (substance and commercial production) and the readily available feedstock used in biogas generation being animal and human wastes. Biogas stoves and lamps are the commonly used appliances for cooking and lighting while for those without installed biogas plants mainly use wood fuel, hydropower, and solar as an alternative energy source.

In the study, it was found out that majority of the households (60.3%) had biogas installed in their households while those without biogas were 39.7%. Meaning that there was potentiality of biogas use in the area.
Several variables were identified that indicated that biogas energy use has a potential of attaining the SDGs.
The households benefits from, reduced amounts of greenhouse gas emissions in the household environment; clean and smoke free energy; reduced time spent in cooking; bio-slurry that provide high quality fertilizer; created time for women and children to engage in education and productive activities; in addition to increased life expectancy and reduced demand of fuel wood.

Although the households assume various benefits achieved from biogas generation, their adoption rate in the area is still very low and the development approaches (top-down) used when implementing the various initiatives play a big part in it.

The results showed that access to biogas knowledge and technical expertise are the main variables hindering biogas adoption besides other factors as the One-Way Anova results reported that majority of the variables had no statistical significant difference among the means. Therefore, the study area biogas economy was characterized by lack of access to biogas knowledge and technical expertise as the main factors; high initial investment; availability of wood fuel; and lack of government support that hinder biogas adoption.

As a means of addressing the above challenges, the Ugandan Government should properly revise the development and implementation policies and frameworks on renewable energies in addition, to putting an emphasis on subsidy facilities to facilitate the adoption rates.

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Annexes

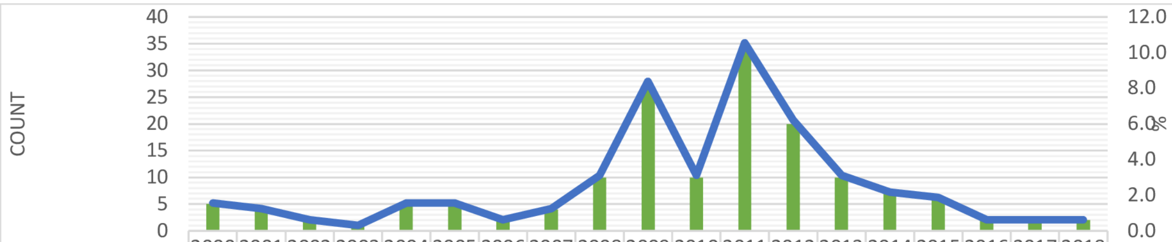
List of the Annex:

- List of figures and tables
- A Fixed Dome Digester in one of the Household Vicinity
- A Household users Kitchen with biogas stove
- Questionnaire Survey guide
- Interview guide

Annex1: List of figures and tables

Table (22): Household involvement in Agriculture Activity

	N	Mean	Std. Deviations	Variance		Percent
Does the household carry out any agriculture Activity	262	1.11	.314	.099		
						Yes = 83.8
						No = 10.4
						Missing = 5.8



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Frequency	5	4	2	1	5	5	2	4	10	27	10	34	20	10	7	6	2	2	2
Percent	1.6	1.2	.6	.3	1.6	1.6	.6	1.2	3.1	8.4	3.1	10.6	6.2	3.1	2.2	1.9	.6	.6	.6

Figure (22): Year of Installation

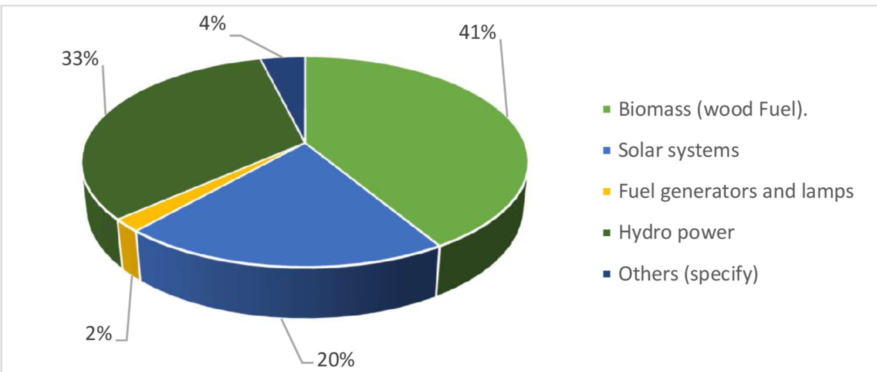


Figure (23): Alternative Energy source

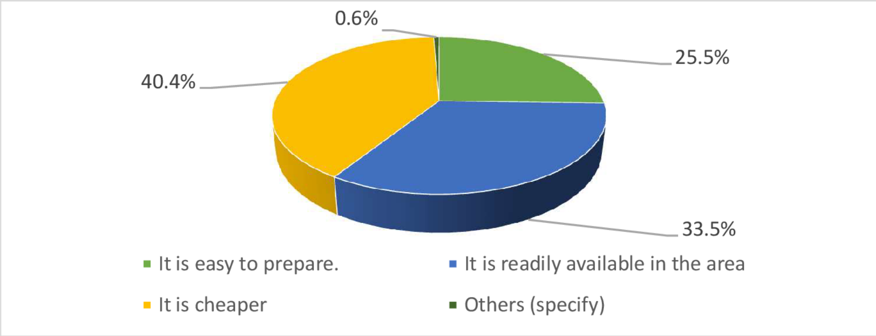


Figure (24): Why the feedstock is used

Annex 2: A Fixed Dome Digester in one of the Household Vicinity

Annex 3: A Household user's Kitchen with biogas stove

Annex 4: Questionnaire Guide

I am a master's studies student at the Czech University of Life Science in Prague and I am conducting a study on Biogas in Uganda and the SDGs: A comparative cross-sectional fuel analysis of biogas and wood fuel; A case of Iganga district, Uganda. My target audience is households in Iganga Municipality Council, Namungalwe, and Nakalama sub-counties.

The purpose of this survey is to help me understand the use of small-scale biogas technologies vs wood-fuel and their implementation benefits in terms of the socio-economic, environmental, health and climate issues in relation to the SDGs among households in the rural areas of Iganga district. This questionnaire therefore is strictly for academic purposes and the response given will be treated with a high level of anonymity. I request you to answer the following questions and all your responses are highly welcome.

Date of Survey	
Sample No.	
Village	
Sub-county	

Dear respondent, I request you to please select one or more options or fill in responses in the spaces where applicable.

<u>**SECTION A. General information**</u>

1.0 Personal information about the household.

1.1	Is the HH male or female headed?	
1.2	Age of the HHH	
1.3	Education Level of the HHH (code*)	
1.4	Occupation of the HHH (code**)	
1.5	Family Size (No. of HH members)	

HH - Household, **HHH** - Household Head

Code*: 1. Illiterate, 2. Literate but no institutional education, 3. Primary, 4. Secondary, 5. Tertiary but did not graduate, 6. Tertiary and graduated.

Code:** 1. Civil service, 2. Business (specify), 3. Farmer (Specify), 4. Manual laborer, 5. Domestic worker, 6. Others (Housewife; Tailor, carpenter, etc. ………… specify if any).

2.0 Basic information about biogas and the related aspects

2.1	Do you have any biogas digester installed? (1=Yes & 2=No)	
2.2	If yes, which type of digester is it? 1. Fixed dome. 2. Floating drum. 3. Balloon 4. Others (specify)	
2.3	Who financed the installation of the digester? 1. Yourself 2. NGO (please write the name) 3. Government 4. Others (specify)	
2.4	What year was the digester installed?	
2.5	Why do you use biogas plant? (More than one answer can be selected). 1. Low cost installation 2. Generates more gas, 3. Easy to maintain and operate. 4. Others (specify)	
2.6	What do you use the biogas for? (More than one answer can be selected. 1. Cooking. 2. Lighting. 3. Heating. 4. Others (specify	
2.7	If yes, besides using biogas, which other type of energy do you supplement it with?	
2.8	What biogas appliances do you use? 1. Biogas cookers 2. Biogas stoves 3. Biogas lamps 4. Refrigerators	
2.9	Which type of feedstock do you feed the digester? 1. Crop waste. 2. Animal waste 3. Human waste. 4. Kitchen waste	
2.10	Why use the type of feedstock? 1. It is easy to prepare. 2. It is readily available in the area 3. It is cheaper 4. Others (specify)	
2.11	If No, what energy source do you use for cooking and lighting? 1. Biomass (wood Fuel). 2. Solar systems	

	3. Fuel generators and lamps 4. Hydro power (UMEME/YAKA) 5. Others (specify)	

SECTION B. Impact of Biogas vs Wood fuel use on SDGs Achievement

Please rate the following benefits of biogas use over fuel wood according to your understating from the highest to least

3.0	**Socio-Economic Assessment**	**Rank** **1-(Lowest) 8-(Highest)**
3.1	Reduces on the time spent in collection of firewood	
3.2	Time spent in cooking is reduced	
3.3	Women and children get time to engage in education and productive activities	
3.4	Creates employment	
3.5	Increases household savings and incomes.	
3.6	Reduces costs of waste removal	
3.7	Increases energy supply	
3.8	Use of bio slurry from biogas increases crop yields	

4.0	**Environment Assessment**	**Rank**
4.1	Reduces on deforestation	
4.2	Reduces on air pollution	
4.3	Reduces on carbon emission in the household environment	

5.0	**Health Assessment**	**Rank**
5.1	Increases on life expectancy	
5.2	Reduces on eye and respiratory infections caused by unclean smoke	
5.3	Serves as a method of waste disposal and sewage	

6.0 Variables for Adoption and Use of biogas in Households

6.1	Access to biogas knowledge and technical expertise are the main variables hindering the adoption and use of biogas besides other factors. 1. Strongly Agree 2. Agree 3. Disagree 4. Strongly Disagree	
6.2	If you Disagree or Strongly disagree, Why?	
6.3	What other factors hinders your adoption of biogas use in households? Please rank from the highest to the least.	
	1. I do not have access to sufficient supply of feedstock (Waste).	
	2. There is no sufficient government support	
	3. Firewood is readily available and accessible	
	4. Financial constraints (Initial investment is too high).	
	5. Biogas is dangerous	
	6. Its more expensive than other sources of energy	
6.4	What motivating factors lead to adoption of biogas technology?	
	1.Easy to use	
	2. Subsides given by the government	
	3. Women and Children get time to engage in other developmental activities.	
	4. Saves money	
	5. Its smoke free	
	6. Time spent on cooking is reduced	

7.0 Policy Approaches

7.1	Does the government and or NGOs involve the community when implementing renewable related initiatives? 1. Yes 2. No	
7.2	If Yes, how does it? Please, select one or more response. 1. Consults the people 2. The Community provides labor 3. It sensitizes and creates awareness.	

7.3	Are the initiatives always sustainable? 1.Yes 2. No	
7.4	If yes. How sustainable are they?	

SECTION C: Other Biogas Adoption Related Aspects

8.What advantages and disadvantages does wood fuel use have over biogas?

a). Advantages

……………………………………………………………………………………………

……………………………………………………………………………………………

b). Disadvantages

……………………………………………………………………………………………

……………………………………………………………………………………………

9 a). Do you have a permanent pit latrine?

i). Yes ☐ ii). No ☐

b). How far is it from the main house? (In Meters)

……………………………………………………………………………………………

c). If you have a biogas digester, how far is the latrine from it? (In Meters)

……………………………………………………………………………………………

10a). Do you as a household carry out agriculture activities?

i). Yes ☐ ii) No ☐

b). If yes, select one or more from below

i). Poultry ☐ ii). Animal rearing (specify, Cattle, Goat, Pigs, etc.) ☐

iii). Crop cultivation (specify) ☐ iv). Mixed farming ☐

c). If Yes, is it for

i). Subsistence purposes ☐ ii). Commercial purpose ☐ iii). Both ☐

11a). Where do you collect your water from?

i). Borehole ☐ ii) Tap ☐ iii). Well ☐ iv) Dam ☐ v). Tank ☐

b). How far is the choice selected in 11(a) from the household?

……………………………………………………………………………………………

Name of the Researcher: Mukisa Phiona Jackline.

Thank You for Your Response.

************END************

Annex 5: Interview guide for Local Government Officials and NGO's

A. Waste Management Section

1. What waste management systems exist in these areas?
2. What kind of waste is collected and how is it handled?

B. Biogas and the related matters

3. What is the potential for biogas generation in these sub-counties?
4. How reliable is the waste generated by households in these sub-counties for biogas generation?
5. What initiatives has the government or NGOs taken to promote the use of biogas energy?
6. What funding is provided by the government and /or NGOs for installation of biogas digesters and biogas appliances?
7. What policy approaches are used by either the Government and or NGOs in the designing, development, and implementation of renewable energy initiatives? And how efficient and effective are they?
8. What approaches are used in the implementation and installation of biogas systems by the government and/or NGOs?
9. What are some of the challenges met by the government, NGOs, and households when it comes to adoption and installation of biogas digesters?
10. How beneficial is the use of biogas energy to households?

S/N	ASPECT	BENEFIT
1.	Socio-economic	
2.	Environment	
3.	Health	
4.	Climate	

11. What common sources of energy are used for cooking and lighting in these areas and why?

12. What challenges exist with the current energy sources being used by the households in general?

Thank You

************END************